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Elementary School Science Teaching

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Foreword

This is an appropriate time for a monograph on science education in the elementary schools. The far-reaching and sometimes frightening expansion of science, particularly during the last generation, has penetrated most of the fabric of American society, and most of the living habits of the individuals who comprise it. The schools and their students have been no exception to this impact of science. In recent years, many Americans have viewed the effectiveness of the nation's schools with a concern sometimes bordering on panic. Specifically, science instruction in the nation's schools has been a prime target for criticism—constructive and otherwise. As a result, science education at all grade levels is in a period of anxious study, of great ferment, and of strategic development.

During the past decade remarkable efforts have been made to upgrade science teaching in the secondary schools. Although science instruction at the elementary school level has been evolving for many years, the momentum of this entire feeling of unrest with science education is on the verge of producing swift and profound changes in elementary school science.

It is therefore a welcome contribution which Dr. Vessel is making to the teaching of elementary school science. Carefully and competently he builds his case for science teaching on the logical foundations of the nature of science and the nature of education; his historical treatment of elementary school science is brief and to the point. Objectively and thoroughly he draws attention to a wide variety of curriculum organizations and classroom procedures. Through careful analysis and illustrative examples, he points out strengths and weaknesses of these as he sees them, but he makes it clear that there is still much room for individual choice by professionally competent people—that there is no "unique and royal road" to effective science instruction. Finally he identifies the more significant current trends in the field, and indicates certain important directions for research and development.

Dr. Vessel speaks from wide experiences as a scientist and educator, as a teacher of children and of adults, and as a seasoned writer and vigorous worker in the field of science education. In this monograph he has made a contribution of distinct value to in-service and pre-service teachers, to elementary school administrators and supervisors, and to lay groups who are interested in improved science instruction for American children.

ROBERT STOLLBERG
Professor of Physical Science
San Francisco State College

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CHAPTER I

Orientation of Science in the Elementary School

This book discusses the problems of teaching science in the elementary grades. To analyze these problems it is necessary to understand what science is and how science became involved in the elementary school curriculum. A brief consideration is given to the elementary science now being taught, including a discussion of some of the teaching patterns and facilities. Since an improvement in science teaching is hoped for, consideration is given to the direction this improvement may take. In this brief exposition no attempt is made to cite the numerous research studies related to the problems of teaching elementary science. It is hoped, however, that the student, teacher, administrator, and layman reading this book may obtain an overview of elementary science teaching; and for those involved in classroom teaching there may also be some specific aids for improving their teaching of science.

What is Science?

One cannot appreciate the problems of teaching science unless he first understands the nature of science. Most of us have had some exposure to science, but few have grasped its essence. It could be said that science is what scientists do. The "doing" represents a continuous search for an understanding of the phenomena in the universe. It is inquiry into the forces and materials of the environment. In pursuing this search, the scientist must be as impartial and impersonal as he can be. He must make his measurements as objective as possible. Furthermore, he must assess the data gathered from his investigations with caution and skepticism.

The scientist may propose a theory which, when sufficient experiments and observations have been made, may "explain" a set of natural phenomena. This theory may also serve as a frame of reference suggesting further problems and relationships for study.

From such studies by scientists, an understanding of some of the forces of nature and the principles of science has been obtained, enabling man to comprehend, predict, and control his environment to some degree. Pure research in science is carried on without concern for its practical value. The knowledge learned, however, represents a capital stock of information to which a technician or engineer can refer. In so doing the engineer applies the principles discovered by research scientists to develop a device or a technique that may enhance our living conditions or broaden our knowledge. Because every aspect of living is affected by such application of scientific knowledge, called *technology*, we are quite aware of this phase of science. Such items as electric lights, television, anesthetics, frozen foods, and jet planes are common knowledge to most of us. But the great majority of people has no knowledge of basic scientific research or even its importance. Yet the technology of science has seldom been the stimulus for scientific research.

> Knowledge for the sake of knowledge, as the history of science proves, is an aim with an irresistible fascination for mankind, and which needs no defense. The mere fact that science does, to a great extent, gratify our intellectual curiosity, is a sufficient reason for its existence . . . To the majority of laymen, science is valuable chiefly for its practical application. But to all the greatest men of science practical applications have emerged incidentally, as a sort of by-product.[1]
>
> . . . science is not technology, it is not gadgetry, it is not some mysterious cult, it is not a great mechanical monster. Science is an adventure of the human spirit. It is an essentially artistic enterprise, stimulated largely by curiosity, served largely by disciplined imaginations, and based largely on faith in the reasonableness, order, and beauty of the universe of which man is a part.[2]

Science is an intellectual search involving inquiry, rational thought, and generalization. This is the technique of science, or what some people have called the science *process*. The discoveries and the interpretation of scientific explanations represent the descriptive knowledge of our universe—the storehouse of facts and principles. This is sometimes called the *product* of science. Both these facets of science are important, and to the scientist they are interdependent.

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[1] J. W. N. Sullivan, *The Limitations of Science* (New York: Mentor Book, The New American Library, 1954), p. 164.

[2] Warren Weaver, "A Great Age for Science," *Goals for Americans* Report of President's Commission on National Goals, The American Assembly, Columbia University, Published by Prentice-Hall, Inc., Englewood Cliffs, N.J., 1960, p. 105.

What is Education?

Education is a developmental process which takes place in an individual as a result of his exposure and interaction with people and other stimuli in his environment. As a result of this interaction the individual acquires a store of knowledge as well as attitudes, appreciations, skills, and thought processes which enable him to utilize his knowledge and prepare him to live in society. Advances in scientific knowledge affect our living, and as a consequence one's education must be continuous to cope with the ever rising problems of a changing society. Thus, one of the primary goals of education is to enable each individual to become aware of his capabilities and to develop them to a maximum. This, it is hoped, will prepare one for a lifetime of continual change.

Why Teach Science?

Modern science, which began about 300 years ago, has been enlarging our knowledge of the environment at an ever increasing pace, and society has become more and more dependent on the technological consequences of science. No aspect of man's life has been unaffected by scientific developments. The air he breathes may be contaminated with smog or radiation particles. Water, the essential component of living things, is in short supply in many areas and in many localities is contaminated by sewage and other pollutants. Medical research has reduced infant mortality and increased man's life expectancy; it has almost wiped out some hitherto epidemic diseases, and surgical knowledge has advanced so rapidly that there are "banks" for some body organs just as there are blood banks. The population explosion may likely be controlled with oral contraceptives and genetics will aid in developing better plant and animal foods. Geneticists together with chemists are probing the nature of the chromosomes which carry hereditary characteristics from generation to generation. Biologists are trying to learn how the cell duplicates itself. The chemical compounds which make up chromosomal material have already been isolated and the future possibilities of reconstructing and rearranging this fundamental life substance seem fantastic. Energy sources and automatic machines have radically altered the social structure, and man has more leisure time and a greater abundance of things than he dreamed of even a hundred years ago.

But why should every individual understand the fundamental nature and significance of science—why not just relax and enjoy the fruits of technology? The following reasons are suggested:

1. Scientific advances and discoveries move inexorably forward at an ever faster pace. In varying degrees they affect everyone in the home or on the job. One cannot call a moratorium on scientific developments; he can only accept the new knowledge, make some decisions, and try to adjust to the new conditions. Science education can assist the individual in making these adjustments.

2. Occupations in the future wil require more and more scientific skills and knowledge. One's thought processes and knowledge will be continually challenged to be flexible enough to fit new occupations as they evolve.

3. Scientific research, because of its size and importance, is becoming more and more costly, and government funds from the citizen taxpayer's pocket are paying most of the bills. For example, the race with Russia for world prestige and power has often prompted crash programs which may not really be necessary. The citizen should have some knowledge on which he can make judgments regarding problems such as sending a man to the moon; compulsory use of polio vaccine; and fluoridation of drinking water. Unfortunately, few individuals at the present time have the knowledge or the ability to evaluate scientific information to make a sound decision regarding such problems. Science education can provide the individual with experiences and thought processes which will enable him to search out and evaluate the evidence presented, or trust the administrative decisions of our leaders when a new scientific or technological enterprise is inaugurated.

4. Man's superstitions and fears result or persist from misunder-

standings of the causes and behavior of natural phenomena. Science continuously seeks physical and logical explanations for the behavior of objects in nature, and it can dispel many of man's suspicions and fears.

5. One should have some understanding of how the scientist operates. There is no simple recipe by which the discoveries of science are obtained. Diverse techniques, varying conditions, and variations in time are all involved in exploring science problems.

6. Science education can develop one's rational thought processes. Perhaps unique to science is the concern the scientist has for truthfully reporting what he has discovered. J. W. N. Sullivan has interestingly summarized this:

> Science is the activity where truthfulness is most obviously an essential condition for success. Its success, in fact, is measured by its truthfulness. Of hardly any other human activity can this be said. In nearly everything else truth is a means and not an end. And if it turns out to be an unsatisfactory means, it is quite natural that it would be replaced by something else. But a scientific man who should misrepresent his observations, or deliberately concoct arguments in order to reach false conclusions, would merely be stultifying himself as a scientific man. He would not be prosecuting science. An advertisement may tell lies, but then telling the truth is not its object. Its object is to sell the stuff, which is an entirely different object. This is not to say, of course, that scientific men invariably tell the truth, or try to, even about their science. They have been known to lie, but they did not lie in order to serve science but, usually, religious or anti-religious prejudices. They were aiming at a different form of "success." [3]

Thus the student of science learns that a criterion for advancement is truthfulness in reporting what one has found from his research.

7. The laws of science have no boundaries, natural or international, and they form a basis for universal understanding. Science has a universality and an objectivity that can be understood by all people of the world, regardless of their languages, colors, or religions. The intellectually honest individual who possesses a scientific attitude will change his ideas if new findings prove his old ideas wrong.

8. Science education also offers the individual an introduction to

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[3] *Ibid.*, p. 173.

the broad spectrum of biological and physical phenomena and some of their aesthetic features. The unique silken thread of the ballooning spider, the crystalline structure of a polio virus, the metamorphosis of a frog tadpole, and a space rocket shot are marvelous phenomena, thoroughly appreciated only by those who have seen them or have some understanding of them. With the ever-increasing leisure time available, science interests and hobbies can make one's life richer and more meaningful.

In planning the purposes for teaching science in the public schools, three groups of students must be kept in mind.

1. The large majority of students will not be specifically working in the field of science or technology, but these future citizens should understand the scientific enterprise to judge intelligently, rather than emotionally, the solutions to those science problems that will have a decided social impact. They should appreciate the significance of the work being done and intelligently criticize and support the pure research scientist and the technician. They should also be able to understand how everyday forces and machines operate.

2. A substantial number of students plan to be craftsmen, designers, and technicians. This group may represent as much as 25 per cent of the school population.

3. The minority of students plan to become research scientists. This very small group represents our hope for future scientific leadership. These students must not be overlooked, for intelligence is the most precious asset a country can have. Our talented individuals must be identified and, as we might do with the talented musicians and artists, provide facilities to capitalize and nurture their talents.

General Objectives for Science Teaching

What then are the general objectives for teaching science? Briefly, they might be listed as follows:

1. To arouse a curiosity in and an enthusiasm for learning about the world in which we live.
2. To instill a store of fundamental knowledge regarding one's self, the environment, and outer space, and how and where to find sources of further information.
3. To develop scientific attitudes and scientific ways of planning, observing, and working through experiences in problem solving.

4. To develop some understanding of the scientific enterprise, the structure of science, and how science has developed.

5. To develop an appreciation of the contributions science has made to man and society and its import for the future.

What is Elementary Science?

Elementary science is concerned with the science education taught in the grades, kindergarten through grade six. Science has been considered an essential part of the elementary curriculum for at least the last ten years. All subject matter areas in the elementary school are interrelated and contribute to the broad objectives of elementary education, but each has some unique contributions to make. Science is not merely a list of facts, it is a habitual pattern of critical thinking and problem solving. Elementary science can provide the child with much knowledge and understanding of the environment about him as well as help develop thought processes that will enable him to adjust to his surroundings, an essential core of experience in elementary education. It is therefore essential that science experiences begin early in the individual's education and continue throughout his life.

Historical Development of Elementary Science

Elementary science appears to be an outgrowth of three facets of education: object teaching, nature study, and secondary school science. It was probably introduced with the advent of object teaching, a method brought to this country about 1850. Object teaching was an attempt to teach the nature of real things directly by using all of the individual's senses instead of formal reading and memorization, the typical pattern in early American schools.

The popular appeal of object teaching caused it to be introduced into many schools. Many of the teachers expected to teach this program had no normal school learning, so they taught whatever science they had learned in high school or college. Thus the high school and college teacher preparation institutions had a profound influence on elementary teaching, including the teaching of science. During the 1850's most science was still largely in a "what" stage—classification and cataloguing of specimens was the major science activity.

College graduates, many of whom were European trained, taught much as they had been taught. Dependence on European training was so complete that some teachers even ordered specimens from Europe for beginning biological studies, unaware that similar specimens were available in their own backyards.

One of the key individuals who had a decided influence on this period was Louis Aggasiz, a Swiss scientist. Aggasiz was invited to give several guest lectures at the Lowell Institute in Boston. From there he went to Harvard; he remained in America for more than twenty years.

Aggasiz was disturbed by the dependence of American teachers on European training and study. After twenty years' teaching at Harvard, Aggasiz made the cryptic comment that Harvard was not a university but a high school, teaching only the dregs of learning.[4] The often quoted quip "Study nature, not books," [5] credited to Aggasiz, illustrated his feeling about the tendency to book study only. Perhaps to demonstrate what he meant, Aggasiz in 1873 organized the first biological field school, on Penikese Island in Massachusetts. Here, in an abandoned barn, were housed both the living quarters and laboratory for his students of marine life.

From Aggasiz's first field school came a number of prominent science educators; among them H. H. Straight, who revamped the inanimate object study at Oswego Normal School at Oswego, New York, and David Starr Jordon, first president of Stanford University and prominent zoologist.

From object teaching, which taught isolated and disconnected facts, was born the nature study movement, which became increasingly popular up to about 1910. In general, the aim of nature study was to open the pupil's mind by direct observation to a knowledge of and love for the common things in his environment.

A number of individuals pioneered in the nature study movement during the period 1884 to 1890, among them Arthur C. Boyden, Colonel Francis W. Parker, the McMurrays, William T. Harris, and Wilbur S. Jackman. Jackman, called the father of nature study, probably did more than any other individual to organize the program. Of special interest are his two books on nature study, *Nature Study* and *Nature Study for Grammar Grades*. In these writings he points out that the purpose of nature study was to get the child to comprehend his environment and to understand how he fits into the scheme of things.

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[4] David S. Jordon, *Science Sketches; Evolution of the College Curriculum* (Chicago: A. C. McClurg & Co., 1888), p. 241.

[5] Dora O. Mitchell, "A History of Nature Study," *Nature Study Review* (September-October 1923), p. 291.

> The final motive for the study of science is to bring the pupil by degrees to a strong realization that he is the focus of innumerable forces about him which so bear upon him, and so limit his life and comfort as to render the knowledge of how they may be resisted, guided, and controlled, an absolute necessity.[6]

While Jackman was promoting nature study at Cook County Normal School (now merged with the University of Chicago), the New York State College of Agriculture (Cornell), began a nature study program. The specific purpose of this program was to encourage the youth of rural New York to stay on the farm. It was hoped that awakening the interest of youngsters in the farm environment would discourage them from flocking to the cities, where work was not available. Liberty Hyde Bailey and Anna B. Comstock were the key leaders of the Cornell program which began in 1893 and continued up through 1915.

A survey[7] made in 1913 of the elementary courses of study of twenty states and thirty large cities showed a general agreement on the aims for teaching nature study. The primary aim was to develop the child's interest in and a sympathy for objects in nature. A secondary aim was to establish a scientific attitude of mind so that the child would investigate carefully and make truthful statements regarding his observations.

Following World War I two changes seemed evident. First was a trend toward teaching the practical aspects of all subjects in the curriculum. Subject matter was selected which was concerned with the life of man and making a living. A second trend was an attempt to adapt subject matter to the various grade levels. Also about this time a much more rapid technological and scientific development began. The nature study movement did not keep up with the physical science aspects of these rapidly changing conditions. A reorganization of science teaching in the secondary and junior high schools began to take place also and this suggested new science content for the elementary grades. Critics of the nature study program said that teachers of these programs were teaching isolated facts instead of principles of science, teaching for mental discipline only, and teaching things of a biological nature for the sole purpose of bringing students closer to religion. The physical sciences were almost excluded. Furthermore, the nature study movement was reported to be unscientific in its treatment of natural phenomena, it fostered emotional love of nature, and it had no pattern or sequence of topics that continued from one year to the next.[8]

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[6] W. S. Jackman, *Nature Study* (New York: Holt, Rinehart & Winston, Inc., 1894), p. 5.

[7] Alice Jean Patterson, "The Present Status of Nature Study in the Elementary School," *Nature Study Review*, Vol. 9 (1913), 293-44.

Until his retirement in 1952, E. Laurence Palmer cf Cornell University fostered the spirit of the nature study movement as espoused by Jackman, Bailey, Comstock, and Bigelow. Although almost a lone voice, his influence through writings and graduate students did much to provide a better understanding of nature study, conservation, and elementary science.

A program of *elementary science* was proposed to replace nature study. Craig [9] was one of the pioneers who developed an elementary science sequence to replace the nature study program. He evaluated a list of selected science objectives and compared them with a list of children's science questions. From these Craig developed an elementary course of science study for the Horace Mann Elementary School.

From 1920 to 1930 many individuals joined the new movement, called *elementary science*. This movement was led by a group at Columbia University and another at the University of Chicago.

Although critics found fault with nature study, an examination of Wilbur Jackman's statements in the Third Yearbook [10] of the National Society for the Study of Education and his two books outlining the nature study program reveals how one of the key leaders of the nature study movement interpreted this area of teaching. It may surprise many to find that most of Jackman's views were not unlike those proclaimed by the advocates of the elementary science program. Many science educators will also agree that the difficulties in nature study were not with the leaders of this program but with poorly prepared teachers and administrators, each of whom interpreted the nature study program in his own way.

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[8] O. E. Underhill, *The Origins and Development of Elementary School Science* (Chicago: Scott, Foresman & Co., 1941).

[9] Gerald Craig, "Certain Techniques Used in Development of Course of Study in Science for the Horace Mann Elementary School," *Contributions to Education*, No. 276 (New York: Bureau of Publications, Teachers College, Columbia University Press, 1927).

[10] W. S. Jackman, *Nature Study*, Part II: "National Society for the Study of Education" (Chicago: University of Chicago Press, 1905).

Merely changing the name of a program does not improve it. However, some of the leaders of the elementary science program tried to capitalize on the good features of the nature study movement and to modernize its content. A major change was the attempt to place emphasis on the physical sciences. An effort was also made to adapt the subject matter to the maturity of the child.

In 1932 the Thirty-first Yearbook,[11] titled *A Program for Teaching Science*, summarized the thinking of leaders of the new elementary science movement. Although Jackman had tried to show how nature study fit into the secondary school science sequence in the Third Yearbook, high school teachers apparently did not recognize that nature study was a suitable foundation for biology, chemistry, geology, and physics.

Perhaps it was the change of name to "science" along with a modernization of content that has slowly led to a recognition of the value of elementary science to the high school science program.

The Forty-sixth Yearbook,[12] titled *Science in American Schools* was issued in 1947. This publication was designed to emphasize the importance of scientific knowledge during World War II and to point up the impact of science on future society. The writers outlined the basic areas of elementary science and summarized the patterns of secondary school science teaching. Of particular interest was the attempt to categorize the objectives of science teaching into the following: *functional information, concepts,* and *understandings;* and *developmental skills, attitudes, interests,* and *appreciations.*

Science teaching was given another evaluation in the 1959 Yearbook,[13] titled *Rethinking Science Education*. Here an attempt was made to synthesize the research that had been done in the field of science education. The emphasis was on science as a "search for order in nature," with accent on the "search"; and the theme carried throughout was that science was understood "as a continuing process of inquiry, not as a set of firm answers to particular questions." One of the greatest values of this book is the detailed pattern offered for the teaching of secondary level science.

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[11] *A Program for Teaching Science,* 31st Yearbook, Part I: National Society for the Study of Education (Chicago: University of Chicago Press, 1932).

[12] *Science in the American Schools,* 46th Yearbook, Part I (Chicago: University of Chicago Press, 1947).

Today most science educators and administrators are aware of the vital importance of elementary science in the total education of the elementary school child. There is also a growing realization that preadolescents are capable of comprehending basic science principles and that it is possible to develop the students' rational thought processes to carry on critical thinking. A greater importance is also being placed on the structure of the elementary science program to make it an effective part of a twelve-year science sequence. Some teachers have suggested that science should be given the status of a fourth "R" in the school curriculum; others, that science should serve as a core program in the elementary curriculum. There is no doubt that the public must become literate in the field of science, that science education cannot begin too early, and that it should never cease.

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[13] *Rethinking Science Education*, 59th Yearbook, Part I: National Society for the Study of Education (Chicago: University of Chicago Press, 1960).

CHAPTER II

The Elementary School Science Curriculum

The curriculum represents the plan or structure for presenting elementary science to pupils in order to achieve the social and psychological aims of education as well as the generalizations of science. Thus, to understand how a curriculum is developed, one must be aware of the general objectives of education as well as the specific objectives for teaching science.

The purposes for providing science instruction were listed in the first chapter. In the elementary school science instruction should enable the child to understand and appreciate some of the natural forces of his physical environment and how they affect him; and insure that the child becomes aware of his capabilities and realizes that he can solve many of his own problems by his own effort.

Bases for Developing a Science Curriculum

Needs of society. The child today needs quite a different kind of education than the child of 1850 needed. His environment is almost totally different; technological developments have altered almost every one of his activities. The parents of most children in school today have had a high school education, and the widespread use of television has minimized the differences in vicarious experiences that existed in children of earlier years. Rich and poor alike now have the opportunity to hear and see the President, visualize the deserts of the West, see the poverty of some nations of the world, as well as see the "good guys" capture the "bad guys."

Social needs demand that a corps of trained personnel be provided to maintain our increasingly technology-oriented way of living. Obviously, the most important general problem in education is concerned with the maintenance of our democratic form of government in the face of imminent technological changes that affect our society. Science should also provide continued enlightenment on the problems of pollution, conservation of natural resources, disease prevention, and public safety. The world of the future will be as different compared to our world today as were the pioneer days. But future changes will occur more rapidly. Perhaps the only positive statement that can be made of our future world and society is that they will be *very different* from what they are today.

It is essential that schools provide an education that will enable students to adapt to such changes readily. It is probable that students would not fear inevitable changes if they had experience in solving a variety of problems all through their school lives and if they were continually confronted with evolving interpretations of cause-and-effect relationships.

It is also imperative that we develop in students a confidence that they can utilize their own abilities to adjust to and cope with new problems, whether they affect one individual or a group. Confidence does not just happen—students must be given the training and experience with processes that develop such an attitude.

Growth and development of children. To develop an effective program of elementary school science, one must utilize the needs, the interests, and the growth and development characteristics of children. From the time children are born, they begin to acquire sensory experiences. As these experiences accumulate they provide children with some concept of their environment as well as tangible meanings to words. The impact of these experiences will vary with the child's home and locality, but rapid technological developments and urbanization provide children many more opportunities for varied experiences than had the children of fifty years ago.

Primary children arrive in the public schools with a large vocabulary. Words such as jet, orbit, satellite, supersonic, television, telephone, atomic, radar, polio, vaccine, cancer, spaceman, gravity, weightless, oxygen and carbon dioxide are not uncommon. They also have had many experiences of a scientific nature, involving both problem solving and knowledge learning. These might include riding various toys, sprinkling water, observing how plants sprout, feeding pets, answering the telephone, turning on television, washing clothes, riding in an automobile, boat, train or airplane, observing rainbows, watching sugar dissolve, seeing rain fall or steam condense on a window, and asking why there are flies, or why water evaporates.

Aside from the variation in science experiences and social responsiveness, children will vary in height, weight, growth, and vocabulary. The task of the primary teacher is to convince her children that she is there to help them and to help interest them in learning. She can capitalize on a number of natural characteristics of children.

Curiosity. The primary child's curiosity is nearly boundless—he wants to know about things around him, *what* they are and *how they work*. He wants to investigate things, to try them out. Each new experience involves some interpretation, and here the teacher is vitally important. Experiences provide opportunities to learn names of objects and thus to build up a vocabulary. The desire for activity is closely tied to the child's curiosity, and many opportunities should be provided for the child to find out for himself.

Limited interest focus. The child is almost totally concerned with *now* and *today*. Even "yesterday" and "tomorrow" have hazy connotations to the majority of primary children. The child's own environment is of most concern to him. It is this area that he should explore. As he gets older, areas outside of his home and school begin to have significance. These experiences must then be related to his home environment to have maximum learning value.

Imagination. The teacher will find a more receptive imagination in her children once they have adjusted to the school situation. Since most children are not hampered by preconceived notions, they are usually quite impulsive and creative. Belief in fanciful creatures, fairy tales, and enjoyment in hearing the teacher read about talking animals are characteristics of children in the primary grades.

By the time the child reaches the fourth grade his interests may likely indicate what stage of development he has reached, and perhaps what he would like to do "when he grows up." If he is stimulated by his teachers, and he has no major health problems, or an unfortunate home environment, the student should still have the curiosity, imagination, and desire to investigate which he displayed in the lower grades.

Health. About the fourth grade age level, differences in height and weight become noticeable and children become aware of these differences. Girls may become physically mature between the ages of 10-14 and as a consequence food and personal health habits become of real concern. Improved manual dexterity and longer periods of activity without fatigue are characteristics of this preadolescent age. Children at this level will also do much daydreaming. This may be an accompaniment of rapid growth.

Hobbies. Preadolescence is the period when students participate in hobbies such as model building, stamp collecting, and raising of pets. There is also much interest in minute details—for example, how long is a jet plane, exactly how far is it to the moon, and how many seeds does a dandelion have? Few subjects in the school curriculum offer such a variety of hobbies and crafts as science. Many great scientists trace their initial interest in science to an experience in the elementary grades where an understanding teacher provided the counsel and encouragement that brought about success and as a result a life-long interest in the scientific field.

Planning and doing. The preadolescent also feels that he can plan his projects and carry them through. Here science can make one of its greatest contributions. The study of pupil generated problems and situations provides ideal opportunities for planning what could be done. The student should be permitted to plan ways to find out and to apply his solutions to simple problems. The planning may involve hypothesizing solutions to problems and testing the hypotheses. With encouragement and teacher interest this can be a real incentive to purposeful reading and learning how to conduct simple research. Some students have learned to read only after getting involved in a science problem situation—a thing that motivated them as they had never been motivated before.

By reviewing his primary school experiences with biological and physical phenomena and relating these to recent experiences, the student should be able to generalize his observations and formulate science principles. Here, too, the student can begin to appreciate cause and effect relationships; for instance, that certain winds and clouds foretell rain in his locality, or that heating usually causes substances to expand.

Associated with the pupil's planning may be study field trips to obtain first-hand information. The field trips may suggest further experiments which the student must design and carry out.

The preadolescent also begins to feel independent. A conscious effort should be made by the teacher to show him how he can learn by himself using a variety of source materials as well as experimentation.

Suggestions to help children learn. So-called teaching does not always result in learning. The person only learns what the teaching or reading causes him to do.[1] This doing does not necessarily mean physical doing; it might be a change in his thinking. Children do not learn the same material with equal speed, because of variations in native ability and previous experience. The teacher can, however, enhance the environment in ways that will encourage learning to take place, creating situations that satisfy the child's basic needs and thus encourage motivation and learning. The home environment and the emotional make-up of the child will also affect his learning ability.

The child's early experiences in school are very important to him, for he may feel that these successes or failures predict his ability as a student. Sometimes he may compensate a failure in one area of study if he succeeds in another. The danger is that a pupil may fail in all areas, and then be ignored. Such an individual becomes a problem student. Some educators feel that a major cause of school delinquency is a feeling of constant failure or personal inadequacy. It is important, therefore, that schools provide students with some degree of success or satisfaction to develop an awareness in each individual that he has worth and can make a contribution to society.

The following are some basic concepts regarding learning which the teacher should keep in mind.

Learning is largely a reorganization of one's experiences. The student depends upon his previous experiences to meet a new situation. If old responses prove satisfactory to new situations probably no new learning takes place. However, if a new situation cannot be immediately solved but causes perplexity or conflict, the student may seek new responses to stabilize his feelings regarding the probair in the balloon got warmer and it soon fit snugly against the glass. The child was asked what he had discovered. He reported that the balloon got larger. "No," said the teacher, "You discovered that *air expands when it is heated.*"

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[1] G. Lester Anderson and Arthur Gates, "The General Nature of Learning," *Learning and Instruction*, 49th Yearbook of N.S.S.E., Part I (Chicago: University of Chicago Press, 1950), p. 26.

To arrive at the conclusion stated by the teacher the child would need to recall previous experiences relating to air and heat and probably perform many additional experiments. He was honestly reporting what he saw. The teacher, however, was so concerned that she teach a principle of science, that she wasn't aware that such a principle to be derived by her pupils required more than one experience. The point of this anecdote is that one experience is seldom adequate to develop a principle. Although teachers may often recognize the need for experiential learning, its time-consuming nature may preclude its use. And in order to do something in science the teacher often draws inadequate conclusions or conclusions from too meagre evidence.

Learning attitudes. Attitudes are emotionally toned conditionings to situations. This has been suggested earlier as an outcome of a multiple learning process. However, attitudes often occur as a by-product of the learning process. Attitudes often are learned from parents and neighbors.

Undersirable attitudes are usually difficult to change. Understanding and, often, personal experience are necessary to change attitudes. Sometimes attitudes are derived from shocking experiences. The writer had a student who always fainted when viewing a spider, because her uncle had died from a spider bite.

To change attitudes it may be necessary to have the student see things with a different perspective. What is the evidence for the desirability of planting seeds during the full moon phase? How does pasteurization affect milk? Does fluoridation of drinking water really interfere with one's health? A fifth grade teacher, aware of the attitude of most students toward snakes, held up a harmless pet bull snake before the class. "We are going to learn about snakes," she said, "and before the end of the year each of you will touch our pet snake." This teacher discovered that the positive approach coupled with understanding was the best way to alter the attitudes of some of her students toward snakes.

Can the teacher elicit honest reactions from her pupils? This will

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depend upon her relationship with the class. Neighborhood pressure, parental reaction, and some religious beliefs may have established the attitudes of a student. If open discussion is encouraged and conclusions are based only on available evidence rather than on bias, the teacher can often encourage some specific thinking even on controversial topics. Sometimes this may help to change the attitudes of students.

Learning skills. Skills are competencies or habitual responses to situations. In science, skills include planning, following directions, observing, experimenting, research reading, research reporting, and safe handling of science equipment. To develop these essential skills the teacher should provide practice in them as it is needed. When a science problem arises in the classroom, scientific processes should be used to find a solution. Frequent experiences in searching for information in encyclopedias and science source books, planning and conducting experiments, and justifying one's findings all aid in developing some of the major problem solving skills. There are also individual differences in skill attainment—one student may require perhaps six or more experiences before the nature and value of a skill is understood, another may grasp its significance with one or two exposures.

The Curriculum Guide

Keeping in mind the objectives of science education, the needs of society, the growth and development and learning in children, subject matter may be introduced to supply the facts and serve as the vehicle to provide the experiences from which the desired skills, attitudes, and knowledge may be attained. This framework, called by some the *strategy* for teaching science, is the *curriculum guide.* The subject matter of such an outline usually considered in the elementary grades centers about the following broad topics or subdivisions of them: the *earth;* the *universe beyond the earth; living things; matter and energy;* and *man's efforts to control his environment.* Science educators have generally agreed that the elementary science program should provide some experiences from each of these large content areas in the elementary grades.

Many states, counties, and communities provide the teacher a teaching aid in the form of a science curriculum guide, or a course

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Understandings	*Questions*	*Activities*
1. The earth is very old, and has undergone great changes in its lifetime.	1. How old is Earth? How has its age been determined?	1. Use IMC filmstrip *Earth is Born*, #566, as a good introductory lesson. This filmstrip presents a fine overview of much of the material to be covered. Also available through the IMC is the filmstrip *Our Changing Earth*, #339, which presents ways for estimating the age of the earth and theories as to its origin.
	How does the surface of the Earth change? Why is it constantly changing?	*Science for the Elementary School Teacher*, Craig, pp. 260–264, deals with the age of the earth and how it is determined by radioactivity. An excellent reference for children and teachers is the August, 1958 *National Geographic Magazine* article, "How Old is It?" p. 234. This section tells of the use and development of the Carbon-14 test for the age of materials. See also and study the pictures on p. 266 of this same issue. Tom Steege, Hoover Elementary School, has developed an excellent lesson for intermediate grades in this area using Geiger counters.
		Refer to Blough's *Elementary School Science and How to Teach It* for three helpful references: p. 122, "The Age of Rocks"; p. 125, "Life History of Mountains"; and p. 127, "Volcanoes."
		See *How the Earth's Surface Changes*, filmstrip #1605, available through IMC.
The tremendous pressure of over-lying rocks sometimes pushes magma against the earth's crust, raising it into hills and mountains.	When magma cools, what kinds of rocks form?	See Schneider, *Science for Today and Tomorrow*, grade 5, pp. 219–221, which gives information in this area and suggests an experiment involving mountain formation. Movie #M750, *Mountain Building*, available from the Santa Clara County Office, has much helpful information for children for the whole unit. Filmstrip #1441, from IMC, *Story of Mountains*, is also very good.
	Name the different kinds of faults. How are they caused?	
	What is the meaning of diastrophism?	Make a world map or globe. Locate and label the principal mountain systems. Mark the location of the most severe modern earthquakes. A report of a class project, "Making a Globe," is in the Appendix.

Source: Palo Alto Unified School District, Elementary Science Curriculum Guide, Fifth Grade, July 1959, p. 1.

of study. The better guides usually include a statement of general objectives for teaching science and specific or short-term objectives. Specific understandings or concepts representing the basic science areas are often listed by grade level. Associated with these concepts should be suggested activities which can be used by the teacher to assist her in developing the desired understandings. Books, visual aids, and other reference materials may also be suggested. A typical page from the fifth grade curriculum guide of the Palo Alto Unified School District of California is shown.

The preparation of a curriculum guide is usually a developmental process. First, a steering committee of teachers may be selected to establish the objectives for teaching science in the area and to set up other guideposts. Frequently a science consultant is called in to aid in the direction of curriculum planning and to involve noteworthy research findings where these may be applicable.

Some science educators feel that the preparation of the curriculum guide is a task for the science expert rather than a committee of teachers. There is no doubt that an experienced individual could prepare a more scholarly and organized sequence of science materials than could a committee of regular elementary teachers. However, the guide is prepared for teacher use, and one of the major tasks is to convince each classroom teacher that the curriculum outline that has been prepared is what she really needs and can use. In the writer's experience, curriculum guides prepared by only one or two individuals are seldom used by the classroom teacher. It seems desirable that the guide be prepared by a steering committee of teachers, with representatives from all grades. This can be achieved by having a committee representative in each school. During grade level meetings science curricular problems can be discussed. In this manner hundreds of teachers in a large school system may be involved in a study project which should upgrade their science literacy. The guide then becomes a composite work, and many more teachers are interested in it and may use it.

Inservice workshops utilizing the guide are necessary to acquaint teachers with the availability of science materials and the techniques for using the equipment as suggested in the curriculum guide. In spite of all these efforts to prepare a good outline, research shows that few teachers really use their curriculum guide even though these teachers may agree that curriculum study and workshop experiences are some of the most valuable inservice experiences offered. Here is a challenging problem for curriculum experts to investigate.

Preparing the Science Guide

Preliminary planning. One of the first tasks facing a science steering committee in the preparation of a curriculum guide is to agree on a basic philosophy of science teaching and to list the objectives for teaching science in the grades. Objectives serve as the *purposes* for science teaching and they also suggest the direction for the planned instruction. Once the objectives have been agreed upon the question arises as to how can these objectives be attained. An array of subject matter understandings or concepts is usually studied to attempt some categorization of these statements in regard to their difficulty and perhaps as to grade level. A commonly used method is to poll the teachers to determine what areas they feel need emphasis. Although this plan has weaknesses, it does provide an inventory of the science teaching that is being carried on, organized largely if not entirely according to subject matter content. What concepts are being developed is difficult to ascertain by questionnaire.

A concept is an idea or a symbol that one comes to perceive from one or more experiences, actual or vicarious. Since it is unlikely that two individuals would have identical background experiences, it is highly improbable that students will develop identical concepts from the same experience. The term *concept* differs little from "understandings," and the writer considers them more or less synonymous in this context.

There are a number of methods for obtaining the major understandings in the various science fields. Most teachers manuals for elementary science textbooks list them. Craig's [3] book has suggested lists which will prove helpful. The Thirty-First Yearbook suggests thirty-eight major generalizations (listed below) to provide continuity in the science program. The biological science concepts are too broad, there is an over-emphasis of physical science concepts, and some minor changes are necessary because of recent scientific developments, but this is a good basic starting list.[4]

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[3] Gerald S. Craig, *Science for the Elementary School Teacher*, 2nd ed. (Boston: Ginn & Co., 1958), pp. 825-70.

1. The sun is the chief source of energy for the earth.
2. Through interdependence of species and the struggle for existence a balance tends to be maintained among the many forms of life.
3. The earth's position in relation to the sun and moon is a determining factor of life on earth.
4. All life comes from life and produces its own kind of living organism.
5. Matter and energy cannot be created or destroyed, but may be changed from one form to another.
6. Species have survived because of adaptations and adjustments which have fitted them to the conditions under which they live.
7. The energy of solar radiation is continually working changes in the surface of the earth.
8. There have been profound changes in the climate, not only of certain regions, but also of the earth as a whole.
9. The evolution of the earth has come as a result of natural forces.
10. Units of time are defined by the earth's movements in relation to the sun.
11. All life has evolved from simple forms.
12. The earth seems very old when its age is measured in the ordinary units of time.
13. Distances in space seem extremely vast when compared with distances on earth.
14. The physical environment has great influence on the structural forms of life and on plant and animal habitats.
15. Man can modify the nature of plant and animal forms through application of his knowledge of the laws of heredity.
16. There is a great variety in the size, structure, and habits of living things.
17. There are processes that go on within an organism that are vital to its continued existence.
18. Chemical and physical changes are manifestations of energy changes.
19. There are fewer than one hundred chemical elements.
20. Every substance is one of the following: (a) a chemical element, (b) a chemical compound, (c) a mechanical mixture.

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[4] *National Society for the Study of Education*, 31st Yearbook, Part I: A Program for Teaching Science (Bloomington, Ill.: Public School Publishing Company, 1932), p. 53.

21. Certain material substances and certain physical conditions are limiting factors to life.

22. Light is a limiting factor to life.

23. Sound is caused by waves which are produced by a vibrating body and which can affect the auditory nerves of the ear.

24. Gravitation is the attractive force that influences or governs the movements of astronomical bodies.

25. Machines are devices for accomplishing useful transformations of energy.

26. All machines, no matter how complicated, may be analyzed into a few simple types.

27. The properties of the different elements depend on the number and arrangement of the electrons and protons contained in their atoms.

28. All matter is probably electrical in structure.

29. The applications of electricity and magnetism in the home and in industry have revolutionized the methods of living of many people.

30. Heredity determines the differences between parents and offspring, as well as the resemblances.

31. The kinetic energy of the molecules determines the physical states of matter.

32. The gravitational attraction between the earth and a mass of unconfined gas or liquid causes the pressure of the liquid or gas on the surface of the earth.

33. Liquid or gas pressure is exerted equally in all directions.

34. Chemical changes are accompanied by energy changes.

35. A change in rate or direction of motion of an object requires the application of an external force.

36. Radiant energy travels in straight lines through a uniform medium.

37. Electricity is a form of energy that results from disturbing the positions or the regular paths of electrons.

38. In a chemical change, a quantitative relationship exists between the amounts of substances reacting and the amounts of the substances that are the products of the reaction.

Some communities have invited scientists to work with the curriculum committee, to suggest important science concepts in their respective fields. In view of the vastness of the science spectrum and the desirability of fashioning the curriculum to community needs, such a procedure is highly recommended.

Selection of concepts or understandings for the grade levels is a vital task and may be done in several ways. The list of concepts may be given to the teachers of various grade levels in the school district. These teachers indicate which areas seem most appropriate to be taught at their grade level. Then the choices are tabulated by the curriculum committee and final selection is made to avoid duplication of topics.

The logic for this pattern of selecting concepts is that the grade teacher usually knows the interests and the growth and developmental characteristics of her children, and those are the criteria for the final selection of concepts. However, because of an inadequate science background, the teacher may often omit important concepts or blocks of subject matter. Consultation with a science specialist can mitigate this shortcoming.

The following is one pattern of subject matter allocation by grades. Such a plan hopes to provide more time for a thorough treatment of the subject. By selectively staggering the topics, it prevents unnecessary duplication and also avoids gaps in the pupils' science experiences.

TABLE 1

SCIENCE COURSE OF STUDY
ALLOCATION OF SCIENCE AREAS FOR EMPHASIS[5]

	Grades							
Area of Study	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Animals	X		X		X		X	
Astronomy		X		X		X		X
Chemistry			X	X		X		X
Conservation					X			X
Geology	X		X		X		X	
Heat		X	X			X	X	
Light		X				X	X	
Machines & Engines		X		X	X			X
Magnetism & Electricity		X	X		X	X		X
Meteorology		X		X		X	X	
Plants	X		X		X			X
Sound	X		X			X	X	
Water				X				

Another method for selecting science concepts is to accept a prepared list from a neighboring school district or a list provided by a textbook publishing company. Involved in the selection may be some question regarding the appropriateness of concepts to one's locality. If such a list is keyed to one textbook, there may be a tendency to rely upon science reading only, and the textbook serves as the principal if not the only reading source. However, it is considered advantageous to use textbook concept outlines because textbook writers are usually aware of the growth and development characteristics of children as well as the psychology of learning. In general, whatever the pattern selected, the concepts in the primary grades are simple or narrow in scope. In the upper grades, with more experiences and the use of elementary experiences to interpret new phenomenon, the student gets a broader perspective and may develop a broader concept. For the primary youngster, the concept may be "plants need light and water to grow." By growing radishes, nasturtiums, and corn seedlings under various conditions, the young student can develop this idea. In the intermediate grades the concept may be "plants use water and minerals from the soil, carbon dioxide from the air, and sunshine to make the necessary plant foods." The topic has become more involved and also more specific. A study of this content might raise questions as to what minerals are necessary for plant growth, how carbon dioxide is obtained from the air, and if electric lights can substitute for sunlight to grow plants.

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[5] Fresno County Schools, Calif., Course of Study, Fresno, Calif. July, 1960.

Once the concepts or understandings have been selected they are arranged into a preliminary outline with suggested teaching activities. At this point a select group of teachers in various grades may be asked to try teaching the concepts, using the suggested activities in their classes. Once taught and criticized by these teachers, the outline is revised and may then be issued to all the teachers.

It should be emphasized that no curriculum guide is a final outline—science subject matter changes continually and so do teachers. Since studies show that many teachers feel curriculum planning offers a most valuable inservice experience, it should be expected that the curriculum would be in a continuous state of revision.

Bases for selecting science content. Although the science areas suggest topics from which specific learnings can be chosen, much selecting must be done. The organization of science content in a particular school will vary depending on such factors as the interest and philosophy of the administration, background of the elementary teachers, and the nature of the community.

It is not possible to teach all the pertinent concepts in one grade level—how, then, does one decide what should be emphasized? The following criteria were proposed by one curriculum committee to aid in a selection of the content materials to be used in a science program extending from kindergarten through the twelfth grade. The committee suggested that the selected *content* in science:[6]

—should contribute to the major concepts and principles of science, giving students the information and understanding in terms of which to "think" in science.

—should be of wide concern to all students, leading to an understanding of man, and of man's place in nature and the world of events.

—should provide opportunities for problem solving experiences.

—should be related to the immediate environment (community resources), giving science a realistic setting.

—should be adaptable to a variety of learning activities, with highest priority on direct experiences.

—should be socially and culturally significant.

—should stimulate desirable attitudes toward and appreciations of science and of the men and women of science.

—should be amenable to integrative treatment of the sciences and other disciplines (broad relationships).

—should aid in developing lifelong interests and leisure-time hobbies.

—should include the frontiers of science (space travel, new chemicals, vaccines).

—should provide situations in which children work together in teams and committees, as well as in independent problem-solving.

—should include opportunities to illustrate career or vocational possibilities for children.

—should be problematical in its challenge (conservation, population growth, health through smog control, world's energy resources).

Anticipated outcomes. Other criteria to be considered in the selection of science subject matter and the manner of presenting this content are the anticipated achievements or changes in the child expected as a result of having been exposed to this science teaching. What do you hope the elementary science experiences will do for the child—what are the anticipated attainments? The following list of outcomes taken from the New York City Guide serves as a good example.[7]

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[6] *Leadership for Science,* Publication of the California Association for Supervision and Curriculum Development (Palo Alto, Calif.: National Press, 1960), p. 84-85.

1. *Concepts:* By the time a child has completed the sixth year, it is expected that he will have developed some fundamental broad concepts concerning the world in which he lives.
   - a. We are unceasingly engaged in efforts to use the forces of nature and to protect ourselves against them when they become destructive.
   - b. As civilization has developed, we have learned to adjust ourselves to our environment and to use and modify the environment for human purposes.
   - c. Knowledge of the world around us is the result of many centuries of exploration and thought by men and women of all lands.
   - d. The more we know about the world, the better we realize how slowly the fund of human knowledge grows, how much there is still to be known, and the limitations of human understanding.
   - e. We try to understand the world we live in by piecing together seemingly isolated concepts, which ultimately form a pattern.
   - f. The basic natural processes occur in cycles such as growth and decay, night and day, and the water cycle.
   - g. All living plants and animals come from similar plants and animals.
   - h. Plants and animals depend upon one another for survival.
   - i. Our earth is only a small planet in a vast universe.

2. *Attitudes:* By the time a child has completed the sixth year, it is expected that he will have acquired such desirable attitudes as the following:
   - a. An inquiring attitude—a seeking for explanations based upon reliable sources.
   - b. A realistic understanding of the values and limitations in the use of the methods of science.
   - c. An exploring attitude, mental and physical, resulting in a continuing eagerness to learn more about the world in which he lives.

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[7] Reprinted from "Course of Study in Science for Elementary Schools, Grades K-6" (1954) by permission of the Board of Education of the City of New York. Pp. 2-5.

d. A social attitude—a realization of the function of every individual in the great scheme of things; the realization that richness of living comes through cooperation and helpfulness.
e. A moral-ethical attitude—directed toward the use of science and scientific advances for the common good, and toward moral and ethical goals.
f. A reverent attitude—wonder at the vastness, age, and complexity of the universe.

3. *Knowledge:* By the time a child has completed the sixth year, it is expected that he will have acquired some basic knowledge about:
   a. His body—how it works and how to keep it healthy.
   b. The food he eats—where it comes from, how it is protected, how it gets to him, what it does for him.
   c. The house (school) he lives in—how and why it is supplied with water, gas, electricity, light, heat, fresh air, drainage pipes.
   d. The community he lives in—how it protects him with traffic lights, fire alarm boxes, and other devices.
   e. The air around him and how it affects him.
   f. The water he uses.
   g. The clothing he wears—where it comes from and how it protects him.
   h. Tools and machines that help him—how they work and why they work as they do.
   i. Toys that amuse him—how and why they work.
   j. His earth—its neighbors in space, its movements, its outward features, its buried treasures.
   k. People that share his earth—how they are alike and how they are different.
   l. Animals that share his earth—what they look like, where they live, how they try to survive, how they can be helpful, how they can cause harm, some that are no more.
   m. Plants that share his earth—what they look like, how they grow, how they can be helpful, how they can cause harm.
   n. The forms of energy; how they are used and transformed.
   o. Materials that help make the things around him—where they come from, how and why they are used.
   p. How he gets from place to place—on land, on water, in the air.
   q. How his ideas can be passed on to others—by sound, light, radio, television; and preserved by printing, photographing, and recording.
   r. How he can live more safely.
   s. How the world's great scientists have benefited him.
   t. Why he must help conserve animal, plant, and mineral resources.

   u. His place in the universe—how the sun affects him, what the stars and other objects in the sky mean to him, how he might travel into space, what he might find on other planets, his place in the immensities of time and space.

4. *Skills:* By the time a child has completed the sixth year, it is expected that he will have developed the appropriate skills to enable him to:
   a. Read a Fahrenheit thermometer.
   b. Make a measurement of weight, length, and time.
   c. Use electrical appliances safely.
   d. Wire a simple electrical circuit using dry cells.
   e. Devise elementary science projects.
   f. Set up and use some simple machines.
   g. Keep a record of science measurements and discoveries.
   h. Grow and care for a plant.
   i. Care for an animal pet.
   j. Determine north, south, east, and west.
   k. Recognize a prominent constellation and the North Star.
   l. Recognize common materials by their characteristics.
   m. Identify a variety of animal forms.
   n. Identify some neighborhood plants.
   o. Identify some common rocks and minerals.
   p. Make a meaningful collection.
   q. Interpret a simple weather map.

It should be noted that most of these skills refer to the applications of science or technology. This may be understandable for these are specific items that can be measured. But one might ask how do these achievements prepare the student to adjust to and participate in the onrush of scientific developments and the continually changing world?

Curriculum planning committees need to keep a number of other factors in mind. Most important are the growth and learning characteristics of elementary children discussed earlier. In the primary grades attention generally emphasizes observation and exploration to develop simple understandings and relationships; in the upper elementary grades, simple relationships in addition to basic discoveries are ascertained by planning and conducting experiments. These experiences should also include quantitative measurements of all kinds to involve mathematics as a useful tool.

Added to these considerations there are still other questions that permeate science curriculum development.

1. Should a topic such as plant life be taught at every grade level? Should it be considered every other year, or perhaps in some other sequence?

2. How much time should be allotted to teaching science? Some teachers allow only fifteen minutes on Friday afternoon for their science instruction, others schedule as much as four hours per week. Challand[8] surveyed the elementary science teaching in Illinois schools and reported that administrators and curriculum coordinators considered 2.7 hours of science teaching a week desirable. However, teachers reported that 1.9 hours a week were devoted to science instruction in the primary grades and 2.4 hours in the upper elementary grades.

3. If skills, attitudes, and the processes of science are as important or more important than the subject matter, how should these skills and knowledge be developed in the science program? The curriculum guide is usually developed around subject matter largely, not around skills or processes.

These are problems for which we have no clear cut solutions. Some research has been done in these areas, but for the most part it consists of personal educational philosophies and opinions. From experience it appears that if a teacher wishes to develop skills or attitudes she must plan her teaching with these objectives in mind, otherwise there will be almost no development of skills or attitudes in her pupils. Research in regard to a number of these problems is discussed in Chapters four and five.

Examples of curriculum guides. A few examples of curriculum patterns are listed here to serve as a guide to those contemplating the development of science curricula:

The New York State curriculum divides the science content into ten areas from kindergarten through the ninth grade.[9]

1. Kinds of living things
2. Survival of living things
3. Keeping healthy

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[8] Helen J. Challand, "An Appraisal of Elementary School Science Instruction in the State of Illinois," *Science Education* 42 (October, 1958), 363-65.

[9] *General Science Course 7-8-9*, State Education Department, Albany 1, N.Y.

4. The earth and sky
5. The atmosphere
6. Energy from the sun
7. Rocks and soil
8. Lifting and moving things
9. Using magnetism and electricity
10. Some common chemical changes

Grade blocks have been established on a K-2, 3-4, 5-6 basis, and a sequential development of activities is set up.

The Los Angeles curriculum suggests a cyclic plan to avoid repetition year after year.[10]

TABLE 2

GRADE LEVEL	PLANT AND ANIMAL LIFE	EARTH	SPACE BEYOND EARTH	MACHINES AND ENERGY
K, 1, 2	Animals	Weather	Sun	Machines
3, 4	Plants	Factors involved in weather	Sun in relation to earth	Magnets
5, 6	Interdependence of plants and animals	Forecasting weather	The solar system	Electricity

The Stanislaus County (California) course of study divides the science content into the following areas: [11]

Botany—Plants
Zoology—Animals
Human Physiology—Human Beings
Water
Meteorology—Air, Weather
Geology—The Earth's Surface
Astronomy—Solar System, Universe
Physics—Force, Machinery
Physics—Heat, Light, Sound, Radiant Energy
Physics—Electricity, Magnetism
Chemistry—Nature of Matter

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[10] *Elementary Science Guide,* Los Angeles City Schools, Division of Instructional Services, Publication No. EC-191, 1956 (tentative).

[11] Stanislaus County Schools, *Elementary Science—A Guide for Teachers,* Fred Beyers, Superintendent of Schools, Modesto, Calif., 1959.

Some elements of each of these topics are studied each year in a spiral development. The spiral arrangement of subject matter attempts to arrange the content on an imaginary coil or spiral with the content restudied at various grade levels. There is no general agreement, however, as to whether a science topic should be repeated each year or every second or third year. Sometimes this pattern is called a sequential or developmental arrangement for the subject matter may be studied in greater depth and detail with subsequent consideration of the topic. The major concepts for *plants* and *electricity* and *magnetism* are listed to illustrate the development of concepts from simple to more complex.

PLANTS[12]

Grade 1. Plants grow in many different places.
Plants have many uses.
Grade 2. All living things are interdependent; plants and animals need each other.
Plants are living things which carry on processes of life; plants grow and change.
Grade 3. Most common plants make and store food.
Seeds grow into young plants.
Plants exist in many varieties.
Grade 4. Plants interact with their environment.
The parts of plants have important functions.
Identification of common flowers, trees, and farm plants is important.
Grade 5. Plants affect people in many ways.
Grade 6. The adaptation of plants to their environment is dependent upon many factors. This adaptation is not a conscious and willful act on the part of the plant.
Plants reproduce in many ways.
Grade 7. Green plants manufacture and store food.
All forms of life interact with each other.
Grade 8. Some plants, especially one-celled plants, are so minute in size and are visible with a microscope only.
The cell is the basic structure of all plants.
The chief elements of living matter circulate into and out of the air and back into the plants (and animals) again.

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[12] *Ibid.*

Electricity and Magnetism

Grade 1. Electricity moves things. Electricity does work.
Magnets are interesting and important.
Grade 2. Electricity is important to people in many ways.
Magnets have a special effect on pieces of iron or steel.
Grade 3. Electricity can be made available from different sources and can be controlled to make things move and do work
Magnetic effects seem to be strongest at the ends or "poles" of a magnet.
Grade 4. Electricity is a form of energy.
Magnets help determine directions on the earth.
Grade 5. Magnets made with electricity are called electromagnets. They are extremely useful.
Frictional or static electricity may be made by rubbing one object with another.
The earth is like a huge magnet, with the magnetic poles near the north and south poles.
Grade 6. Knowledge about the electron improves the understanding of electricity.
Proper electric circuits control an electric current.
Electrical energy may be used for many purposes.
An electric motor changes electrical energy to mechanical energy. Some examples are food mixers, shavers, floor polishers, vacuum cleaners, phonograph turntables.
Electrical energy is utilized in communication. Electricity is used in the telephone, telegraph, radio, and television.
Grade 7. Electricity can be produced in several ways.
An electric current can be controlled.
Grade 8. An electric current is an essential part of radio and television transmitter and receiver sets.

This outline attempts to present a sequential development of concepts beginning with the simpler understandings and progressing to the more difficult ones. One might question the sequential arrangement of some of the topics, but this may be due to the brevity of the statements quoted. (An explanatory paragraph following a number of theses conceptual statements was omitted here because of space limitations.)

Kansas City (Missouri) suggests two biological and two physical science units for each grade level.[13] The same general topic is repeated every second or third year to enlarge the scope and treat more complex components of this topic. In grade one is a unit on "The Sun," in grade three is a related topic called "Earth and Sky," and in grade five, "The Solar System" is recommended.

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[13] *Science Experiences in the Elementary School,* Curriculum Bulletin 82, Public Schools of Kansas City, Mo., May, 1952.

The Resource Unit

The curriculum guide provides an outline to aid the teacher in preparing a *resource unit*. From the resource unit she may prepare a *teaching unit*, and finally the teaching unit may be parceled into suitable teaching segments or *lesson plans*. A brief discussion of each of these teaching guides follows.

The resource unit is a collection of science materials and activities related to a particular topic. The term "resource" unit indicates that the unit is more than a *teaching* unit. It is written for the teacher to provide a source of materials from which she can select suitable topics and materials to teach her children. Usually this is aimed at a group of grades such as the primary, intermediate, or junior high school level, but it could be written for a particular grade. In general, a resource unit includes:

Title: e.g., Water, Electricity and Magnetism, Pets

Introduction: Briefly indicate the social and scientific significance of the unit, and why it is important to children of this age level.

General objectives: These are brief statements specifying what outcomes might be expected or are desired from the teaching materials in the unit. Sometimes these objectives are listed under a number of headings such as: (a) understandings; (b) skills, and (c) values (attitudes, appreciations, and interests).

Content: This is the body of the unit. It may consist of a sentence-outline, or a series of paragraphs which discuss the over-all subject matter. Although the content is presented in a logical outline from an adult point of view, it may not be psychologically correct to present it in this form to children. In planning with his children the teacher may discover that quite a different sequence of topics is desirable.

Activities of the unit: This includes a description of the projects, demonstrations, experiments, and field trips which can be used for searching out data and for culminating or summarizing the unit. These activities must be described explicitly to be of help to the teacher. For example, a particular film or a story may be suggested to arouse an interest in the problem; a series of available charts or a specific arrangement on a bulletin board or a science table may be suggested as aids to the teacher for motivation, expansion or culmination of the unit.

Evaluation instruments and procedures: Often the types of instruments are suggested with reference to where they may be obtained. More desirable are samples of examinations that can be used with rating scales and suggestions for administering the tests. Tested methods of recording anecdotes and evaluating student-made models, sketches, and student discussions should be included.

Teaching materials and sources: In the resource unit these materials are divided into those suitable for teacher use and those for children's use. There is a tendency to suggest enormous lists of books and pamphlets. This is of little value—the teacher, overwhelmed by the number of references, usually uses none of them. However, a careful annotated selection of books, pamphlets, periodical articles, films and film strips, and charts is most helpful. Sources of individuals who are available as speakers or who may serve as sources of information should also be listed here.

In summary, then, the resource unit is a source book of localized information which can be used by the teachers of a district. Some school administrators keep resource units on file for teachers' use and request that teachers who have used the material add their experiences and reactions to the unit. This becomes a most valuable teaching asset for the school and serves all the elementary grade teachers.

Teaching unit. The teaching unit is usually developed from a resource unit. For example, from a resource unit titled "Water, A Valuable Natural Resource," the second grade teacher selects a number of concepts which she feels she can develop with her children. This is a part of her classroom study of community life. The concepts she selected might be as follows:

1. Water is almost everywhere.
2. Water is carried in pipes from its source to homes and other buildings.
3. Water can be used for many things.
4. Water can evaporate from things that are wet such as lakes, aquaria, and washed clothes.
5. When moist air is cooled, water may appear in several forms.

Next she plans how she will motivate her class to become interested in studying water, or how she can relate this topic to the previous study of the community.

From her first lesson about water the children may have decided on one major problem—where does water come from? They have also made plans to carry on some simple experiments which they hope may help them to determine if there is water in bread, dry cereal, and carrots, if there is water in the air on a sunny day, and what frost, hail, and snow are. The teacher then plans how much time she must have, what materials may be needed, the future direction of the teaching unit and the probable culmination.

It should be noted that the teaching unit *develops with the help of the children,* and that it cannot be rigid if it is hoped to get full pupil participation. Where experiments are suggested, children can often bring needed materials for experiments from home.

Lesson plan. The day-to-day strategy which the teacher prepares involves the lesson plan. This may be very detailed for the beginning teacher, but quite skeletal for the experienced teacher. Essentially, it consists of four items:

Why the lesson is worthwhile; that is, the aims you hope to achieve by teaching this lesson.

What will be included in this lesson and what materials will you need to teach the lesson.

How you will go about teaching this lesson. Here is outlined the motivation, the content (including reference materials), and finally the conclusion.

Evaluation. How you can test for the aims that were set up for this lesson. In what ways could this lesson have been improved? What was the children's reaction to this lesson. (The major portion of this topic is entered *after* the lesson has been taught.)

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CHAPTER III

The Teaching of Elementary Science

Patterns of Organization

Although the curriculum guide provides an outline of science teaching, the presentation of learning experiences is an individual matter built around the personality and capabilities of the teacher. Many effective science teaching skills are essentially the same as skills employed in teaching social studies, mathematics, or reading. However, a number of patterns for presenting elementary science are evident in the schools.

Developmental approach. The developmental approach is perhaps the most prevalent pattern of teaching science. Almost all science textbook series are organized on this scheme. The program is set up by first selecting all the basic science generalizations thought essential to a child's education. These are then arranged on a graduated scale, from the simplest to the most complex. Then follows a selection of concepts or generalizations which are thought suitable for the various grade levels. The simplest concepts are taught in the lowest grades. In some instances the same subject matter is considered in each successive grade with varying degrees of difficulty. The pattern is often designated a *scope*-and-*sequence* arrangement. The scope of the subject matter as well as the sequence of topics is indicated for each grade. This will be recognized as a form of the spiral or developmental arrangement discussed in the previous chapter on curriculum planning.

There is a tendency for teachers who use this teaching approach to be concerned with subject matter only. Little concern is given to individual differences in pupils. Students in the fourth grade read textbooks in science for the fourth grade while those in the sixth grade are exposed only to sixth grade books. This practice persists in spite of our awareness that an average fourth grade class may easily vary in reading ability from the second to the sixth grade, and the variation in science ability must be equally great. However, this approach does provide a structured program with some continuity and the possibility for a long range development of science topics. This is an argument of first importance in defense of this teaching approach.

This subject-centered approach has been the traditional pattern of teaching. The recent nationwide criticism against teaching science applications only and "talking about science" suggests that a resurgence of interest in this pattern of teaching may likely occur.

In brief, a structured or developmental science program is essential in the elementary grades:

1. To provide some guidance and security, particularly to the teacher who has had a cursory background in science.
2. To provide a sequential development of science without large gaps and needless repetition of content.
3. To assure a balance of physical and biological science topics.
4. To show that our knowledge of science is developed by piecing together fragments of information and new discoveries into larger components such as theories and generalizations.

Incidental or accidental approach. Science content handled in this way usually has no pattern. The teacher hopes that her students will bring up objects of science interest; or she may teach a lesson on magnets, birds, or wild flowers. Unfortunately, too many teachers teach all their science in this accidental manner. Some will argue that they are capitalizing on the children's interests by presenting science in this way. Although this may be partly true, it is also known that adults can easily influence children's interests.

An incidental science experience *may* serve as a motivating lesson for a more detailed study of a particular topic if the teacher has an interest in science. Such a teacher may present a wealth of science learning opportunities. On the other hand, a teacher lacking science interest may present little or no science. Certainly any good teacher would capitalize on an unusual science event, such as an epidemic of measles, a ride in a space capsule, or a spectacular fire. These unusual circumstances demand immediate consideration, even though it may be very brief. Without any doubt, science education is much too important to rely on accidental teaching alone to present a science program, even in the primary grades.

Integrated approach. An integrated approach to science teaching usually involves a unit teaching plan. Social studies especially are closely allied to elementary science topics. The social studies problems concerned with the home, school, neighborhood and community, offer many opportunities for science experiences. Topics such as personal health, public health, communication, transportation, safety, food, clothing, shelter, water and conservation offer many opportunities for developing science activities.

Science also relies on the language arts and the use of art skills. Curriculum workers testify that science activities can be a tremendous incentive to improve a student's reading, language, and art skills because science provides some purpose for learning these skills.

But to provide science learnings in the integrated teaching approach the students should do more than just enumerate or describe science phenomena in these integrated units. To consider it science, the pupils should explore the problems, make measurements, devise experiments, and draw conclusions. A child that observes a weather vane to find the wind direction is studying science; one who is told that the wind is from the northeast is not really participating in a science experience.

The following is an example of an integrated science experience which occurred in a fifth grade class. In the social studies unit the students were studying the Westward Movement. The teacher wanted to involve a science unit in this topic and she did it in this way. A student committee reported that the pioneers crossed the Mississippi River and moved westward. The teacher raised the question, "*How* did they cross the river?" No thought had been given that there were no bridges or ferry boats to aid in crossing the river. How was the crossing made?

The answer required library research and on the following day the report made was that a raft had been the means of transportation. To demonstrate this, a student made a model raft from the wood available in the classroom and displayed it to the class. The wood he used was very pitchy pine—when the raft was demonstrated it did not float, but sank in the water! This immediately raised further problems—what kind of wood was used to make rafts, what kinds of trees grew in the locality, and so on. One committee reported on the trees found in the Mississippi Valley. After the raft was reconstructed of lighter wood, the question arose as to how the pioneers could be sure where the raft would beach on the opposite side of the river. Here was another problem, one that involved some interesting mathematics. How fast was the river current? At what season of the year was the crossing made? Other problems that were mentioned but not explored were concerned with flotation of objects and buoyancy. It took the class a week to get the pioneers across the river, reported the teacher, but the class had never enjoyed a more exciting week. From test results the class seemed to have attained some understanding of plant geography and relative motion, and they also had some experience in problem solving.

In general, successful integrated teaching can only be carried out by a distinctly superior teacher. She must know how to organize and handle student committees and she must have a good background in all the subject fields of the elementary school curriculum.

Where little or no time for science teaching has been allotted, some administrators propose incorporating all the desirable science experiences into the present curriculum pattern in some integrated fashion. Social studies units are usually used as the core, and science areas are sandwiched into appropriate units. Science experiences that do not fit in with the social studies may be incorporated into the language arts or mathematics. In one instance, the enthusiasts recommended utilizing the language arts to initiate experiences in plant growing and the use of arithmetic to serve as the vehicle to teach matter and energy. Only a blind faith in the value of total integration of elementary subject matter could account for such proposals. This kind of forced integration of science is like the tail wagging the dog. Science which uses mathematics and language as a means of measurement and communication is dragged into the teaching program as an object incidental to language and mathematics. Certainly most science educators would agree that science should be integrated where it logically fits into the unit pattern, but one can hardly call it science teaching if it loses its identity as science in a mass of descriptive words or arithmetical processes.

The integration of science subject matter requires most careful and deliberate planning. Several difficulties usually occur when integrated science teaching is attempted:

1. Science experiences often serve merely as a motivating device for other subject matter.

2. Integrated science too often consists of reading about science, recipe-type experiments, trick demonstrations, and talking about science.

3. Science often loses its identity as science because there is little concern for the *processes of science*. Emphasis is only on the applications of science or the products of technology.

4. Some areas of science do not fit into the integrated pattern and so are omitted. Topics such as outer space, gravitation, and sound and light are quite difficult to fit into a typical social studies core program.

If appropriate, the unit taught can be a science centered unit with other subject matter integrated where practicable. Since science is the process wherein man is exploring his environment to discover if any pattern or conformity exists, then a science core approach is fully as defensible as is the social studies core.

Eclectic approach. In practice most good teachers utilize many of the above methods to teach science. First of all the teacher would select a unit suggested for her grade level. She may then create an incidental experience to initiate the science unit. She may involve the mathematics, social studies, and language periods to make the science study more meaningful.

Unfortunately there is no die from which can be cast all good science teachers. Individuals vary; some are quite creative. The community environment, administration, teaching facilities and materials, and most of all the individual's personality will determine what teaching techniques should be used. If a single model for the successful science teacher must be selected, it would probably be the self-directed or creative individual who could make the most of his teaching situation, whatever the conditions.

Incidental science items should certainly never be overlooked, but science is too important a part of an individual's life to be taught by accident only. A planned science sequence is essential.

Seasonal phenomena should be included in the elementary science sequence. Children from Arizona, Florida, and Hawaii may have no idea what snow is really like; on the other hand, children in the northern states should study snow when it is on the ground.

Teaching units relating to conservation, health, communication and transportation provide many science concepts that could be developed in an integrated type of science teaching. In other units intriguing problems may arise which may require brief scientific investigation to provide the answer. For example, how does a forest-covered slope conserve water? How can a rocket operate where there is no air? What changes will occur to ships loaded with wheat as they move from the St. Lawrence River into the salt water of the Atlantic Ocean? Problems such as these provide experiences in scientific thinking and research and may also aid the pupil in understanding the interrelationships of science to social studies.

Procedures Commonly Used in Teaching Science

The emphasis on science is so recent that it is still encumbered with many obstacles. Many desirable teaching methods in other fields can be adapted to the teaching of science. But science teaching has some unique features.

Realistically, there is little good science teaching in the elementary schools. Too many teachers still associate science teaching with memorizing a list of names or facts, or holding a recitation on a science reading lesson. One might call this an orthodox approach to science teaching although most science educators would not even agree that it was science teaching!

Reading, recitation, and writing. This is undoubtedly the most common method of teaching science. The teacher assumes that if the student has read the science book and can name the kinds of clouds, describe machines, or list major electrical inventions, he has learned science. Here the teacher confuses science teaching with the teaching of spelling or arithmetic. You merely learn the spelling words, and memorize the multiplication tables or the preamble to the United States Constitution. In this kind of teaching emphasis is on what science has discovered—the *products* of science, not the *process* whereby the discoveries were made. Such a program is not science teaching. This is not to say that reading, writing, and language have no place in the study of science. Learning to locate and abstract research materials, writing reports, and giving oral presentations are all essential in the investigation and reporting of science problems. It has been testified often by remedial teachers that science problems carefully chosen usually stimulate the need for reading, providing it is done for a pupil-recognized purpose.

Demonstrations. Demonstrations as a pattern might be considered an improvement over merely reading and memorizing science materials. The teacher provides a visual experience of the phenomena which is better than reading about it. Unfortunately, there is a tendency for all demonstrations to be performed by the teacher. The teacher reasons somewhat like this: "After all, I can make a far better presentation than any student or group of students. Observe what happens in this experiment and record it in your notebook!" So the teacher gets the practice, and probably most of the learning. Too often the demonstration is something novel, and the student may consider it a magical stunt. This defeats one of the specific objectives for teaching science—to become aware that science is not a supernatural phenomenon. Also more often than not, the demonstration is a display of something the child has already seen before so it may bore him.

There are, of course, occasions when demonstrations are necessary. If it is desired that all the students be shown how some piece of apparatus is used, the demonstration may provide the students with a common vicarious experience. At other times the equipment or materials may be too costly to permit student use or it may be desirable to demonstrate the materials to save time. Concern for extensive coverage of science content and the cost of materials are the reasons most frequently cited for emphasizing demonstrations in science instruction, but recent state and federal financial support such as the National Defense Education Act have partially improved this situation.

Properly used demonstrations can make a valuable contribution to effective science teaching. The following criteria should be observed:

1. The equipment used should be simple.
2. The purpose for the demonstration should be clear to the pupil as well as the teacher.
3. The demonstration should be pre-tested. Although an experiment that "doesn't work" can provide the basis for an excellent science lesson, the diversion may often destroy the purpose for the demonstration.

4. The demonstration should be clearly visible to all members of the class.

Radio and television. In the last thirty years programs dealing with science have been presented by radio and during the last ten years television has also been used. The purpose for most of these programs has been to stimulate or supplement the science teaching occurring in the classroom.

For six years the writer was closely associated with a science radio program whose objective was the improvement of elementary science teaching. A fifteen-minute broadcast was provided once a week. To make the program as effective as possible, guide sheets were prepared several weeks in advance, defining the new terms that would be used and also suggesting some questions that would be answered by the broadcast. References were given to the curriculum guide and to other source materials available to the teacher. Whenever an activity was possible, the pupils were furnished most of the materials and instructions for carrying out the activity as well. During the broadcast the students were led step by step through the special activities. Students were encouraged to complete some activities in the classroom and, where possible, to carry on others at home. The programs were all placed on tapes so that classes could hear them again or those classes that were unable to listen at the designated time could also take advantage of the presentations.

Most of our major cities have utilized radio broadcasts as one means of implementing science instruction in their schools and only the greater effectiveness of visual television is supplanting this medium of instruction.

One of the serious problems with such programs is the grade placement. When topics are aimed at the fourth and fifth grades, the primary teachers complain that it is too difficult for their children whereas the sixth grade teacher may insist that it was too simple for his pupils. However, for most classes it can be said that the children learn some science as a result of this exposure.

The use of television has also provided frustrating problems, but the full potential of this medium has not yet been explored. Some results of the experimental work done so far are discussed in Chapter Five. When one realizes that some elementary children spend almost as many hours watching television as they do in school, the possibilities of using this medium for education seems unlimited. Presently, more than 100 schools have closed-circuit television, and every day more schools are developing such facilities. This is also an encouragement to team teaching. Science educators do not agree with those teachers who believe that a fifteen-minute exposure to a radio or television science program will satisfy the need for science teaching in an elementary grade. Too often has the writer heard a teacher quip after a fifteen-minute science broadcast, "Well, there's your science for the week!"

However, the advantages of radio and television programs are many. The expert teacher by radio or television can demonstrate or describe science activities which the classroom teacher may be unable to do. A new course of study can be carefully interpreted by the telecaster and some examples presented to help the classroom teacher understand certain exercises. Television may also be used by students to present their own programs summarizing their classroom and home research in science; there are many other possibilities.[1]

Experimentation. Anyone who has worked with elementary children knows that most children wish to actively participate in learning situations, whenever that is possible. Planning, experimentation, and laboratory work may be involved in the science lesson, and whenever possible, the pupils should help plan the experiments and conduct them. Experimentation may be of two types—merely following the directions to find out if a principle can be illustrated, or investigative in nature, in which no clear-cut plan for testing is outlined.

The first of these might be classed as an exercise or a recipe type of experiment. It usually lacks the luster of discovery and the unknown. It is quick and to the point, however, so most teachers use it. Occasionally this type of experiment may be desirable; for example, to familiarize students with new equipment or procedures they are to use.

Experiments may or may not be those suggested by a book. The unfortunate nature of many textbook experiences is that they propose to "prove" something and the explanation can be found in the same chapter. Such "cookbook" types of experiments merely verify what the student already knows, and as a result the "experiment" is little more than a manipulative exercise. It is quite obvious why students might find science boring if this is the only kind of experimenting they are permitted to do.

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[1] The following are only two of many references on the use of television: John R. Martin, *Two-Way Closed-Circuit Educational Television,* Research Report No. 948-3, 948-4 (Cleveland, Ohio.: Case Institute of Technology, 1957); and *Television in Education,* U.S. Office of Education Bulletin No. 21 (Washington, D.C.: USGPO, 1957).

Investigations suggested by problems raised by students are far more exciting, although more likely than not these problems have no clearcut answer or solution. This kind of teaching always involves more time, sometimes more materials, and possibly more space. But the interest and learning that results from this type of teaching is superior to and far more exciting than any of the formal methods of teaching.

Field trips and excursions. These are an essential part of one's learning experiences. A field trip may be used to stimulate interest in a major problem; it may be used to raise further problems in a study already underway; it may be used as a culminating activity to illustrate applications of methods which the pupils have been studying, or it may serve to gather information which can only be found outside of the classroom. In general, the following four items should be considered in the planning and conduction of field trips to make them effective:

Preliminary planning. The class should decide that the trip is desirable. Some of the preliminary problems of the teacher would involve permission to visit the area, the need for a guide at the site, the duration of the trip, parental consent, facilities for transportation, location of comfort stops if necessary, and what to do if a pupil suddenly became ill.

Pupil-teacher planning. This is the actual planning to make the trip worthwhile. Care must be taken that the trip is not so stilted that it loses much of its value. On one trip, a fifth grader cautioned a new student, "Don't look at anything carefully because you'll have to write about it when you get back to class."

The selection of clothing and other personal equipment must be decided upon. Specific questions should be formulated to give focus to the trip. Written standards of behavior to be observed by all students during the trip are most important and should be discussed thoroughly before the departure.

Procedure during the trip. The teacher must be enthusiastic about the excursion. She should plan to use the travel time, if it is some distance from the school, for such things as singing songs and playing games. For older children a travelog check sheet that points out objects of interest enroute may be desirable. Free time should also be allowed during the trip at which time the students can compare notes, perhaps take some pictures, or ask some questions of their own. Summarizing some of the experiences of the field trip before starting back may be useful for some questions may arise which can best be answered while still at the excursion site.

After the trip. The class should evaluate the entire field trip. Did the trip accomplish the purposes set up? What further problems have arisen? Who will write the letter of appreciation? How can the learnings from the trip be best summarized? Was the conduct of students in accordance with the agreed rules?

Field trips carefully planned can be a most valuable science learning situation—unplanned trips, however, become only a holiday away from school.

Projects and science fairs. These consist of individual as well as group or class activities. The popularity of science fairs has aroused a new interest in student projects. This is especially true in the fourth, fifth, and sixth grades, for the pupils are mature enough to do reading and research on their own. Science fairs are considered a necessary evil by some teachers but the most successful and valuable projects are those that provide opportunities for research. Such projects provide an opportunity for the student having special interests and needs to explore them further under the guidance of a teacher, or a science expert in the community.

Some teachers require that all students do a science project or a research report. This usually poses problems for the teacher. The student may not know what he should do to begin once a project has been decided upon and he will immediately seek help from the teacher regarding directions and source materials.[2] Teachers who have used this plan successfully suggest that a list of suitable projects and topics be made available to the students, and that a list of reference materials and their location be posted. Another suggestion to the teacher is that the student should not commence with a project until he has had a number of science experiences in the classroom to illustrate the pattern of scientific thinking and research that he will employ in carrying out his project.

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[2] These two pamphlets may be of some aid to the teacher: *Sponsors Handbook;* and *Thousands of Science Projects*, Science Service, 1719 N. Street, N.W., Washington 6, D.C., 1957.

Problem solving activities. Problem solving has a host of aliases, among them critical thinking, logical thinking, investigative activities, reasoning problems, creative thinking, and inquiry. Although in no way limited to science teaching, problem solving can be well exemplified in the teaching of science. This approach, with sufficient practice, can develop most of the desirable attitudes usually listed as science teaching objectives. It should also be pointed out that the traditionally taught "scientific method" is not realistic, for there is no single method. Scientists do not attack every problem utilizing the five or more neat steps one by one. Any and every method that comes to mind may be employed by the scientific investigator. But, solving science problems can provide a variety of experiences in scientific thinking. This approach also offers a number of other advantages:

The students may suggest and work on science problems of their own choosing. Motivation is usually high.

Practice in all aspects of the scientific process is possible—comparing, evaluating, hypothesizing, testing, retesting, researching, summarizing, and concluding.

The teacher need not know the answer to the problem—in fact, this pattern of approach thrives on an "I don't know; perhaps we can find out" attitude on the part of the teacher. *But the teacher must be interested in finding out.* "Don't tell them all you know" is a good admonition for most teachers in such a situation. It is very likely that in many situations the teacher really will not know the answer and this should be no obstacle to an excellent problem solving lesson. In this way the teacher can learn with her pupils. Many an excellent teacher has admitted that she learned much of her science by learning it with her students. If it is true, as has been estimated by some crystal ball gazers, that eight-five per cent of the future scientific information will necessarily be learned outside school, then this is a pattern with which every teacher should become acquainted.

Problem solving teaching is exciting teaching because it is usually of personal interest to the student. He may very likely continue this study during his free hours as well as at his home.

There are some disadvantages listed by beginning teachers when they first attempt to use the problem solving approach. The teacher is unsure of herself because she doesn't know the answer or solution to the pupil-selected problem. In other subject areas she is expected to know the informaton and she *can* give students the answer. Few textbooks are written in this manner because authors cannot predict just what problems and questions will arise in the classroom. Some directive questions may be of help to get the teacher started, but experience is needed to carry this on successfully.

It is time consuming. Seldom will all the necessary information be found in one book or be derivable by one simple experiment. Students get carried away with the problem; sometimes the teacher does, too.

It may require more equipment and space in the classroom to carry on the experimentation and project work.

Problem questions that arise in the elementary grades are both varied and numerous. Does a snail find its food by sight or by smell? Will a compass be affected by anything other than iron? How fast does an ant travel? Will a pan of boiling water placed in a refrigerator freeze faster than an equal quantity of tap water? How can an iron ship float? Why does a boiled egg get hard but a potato get soft, when cooked? Will a siphon work in a vacuum?

These are a few examples of the many kinds of problems that arise in the classroom. They may or may not be related to the topic under discussion, but they do offer opportunities for the pupil to solve personal science problems with some teacher guidance. The teacher aids the student in clarifying his problem. She then asks how he might go about solving it, for she very likely doesn't know the solution either. The student's research may likely involve requesting information from the principal, the janitor, and the nurse; it may involve the use of encyclopedias and trade books; and more than likely it will require experimentation. Although a time-consuming experience, it is usually a very thrilling, worthwhile learning experience for the student and teacher alike. Not only does the pupil learn what the scientist knows, he understands to some degree *how* the scientist *came to know*, or how the scientific knowledge was discovered.

In the solution of the problems mentioned above, two approaches are usually used—the *inductive* and the *deductive* approach. Although they are separated here for identification, problem solving usually involves both approaches in its operation.

Inductive approach. In the inductive approach, the student accumulates a large number of observations and then summarizes his findings with a general statement. In the primary grades variation in leaf shape may be discovered by comparing the shapes of many leaves from one tree such as an elm or a maple. The teacher may mount four or more leaves individually on sheets. These are placed on the table and each pupil compares his leaf with the mounted specimen by superimposing it on each of them. With many comparisons the child generalizes in his own words that leaves from the same trees are not exactly alike.

A question such as the following may arise: What happens to the length of a piece of wire if it is heated? A piece of iron wire is measured before and after heating. From this experiment it is concluded that metal wires lengthen upon being heated. However, the evidence presented is that iron wire only behaves in this way; to make a generalization, requires that the same experiment be done using brass, copper, and aluminum wire. From the results of these experiences the student may then generalize that wires made of these materials get slightly longer when they are heated.

The inductive approach is usually exciting to the pupil because the answer or generalization is not known to him. The *thrill of finding out* or *discovering the solution* is perhaps the essence of this approach.

The deductive approach. In the deductive approach a general rule or principle is tested by applying it in a specific situation. For example, it might be stated that all metals expand upon being heated. In this instance, the student might proceed to heat a piece of iron wire to see whether or not it lengthened. From this experience he may conclude that the principle was correct and that he need not test further. Iron, however, is only one metal—many other kinds of metals should be tested. Too often teachers assume that one or two experiences are adequate to understand a principle.

This difficulty may be further illustrated by an exercise many teachers use to demonstrate that fire needs oxygen to burn. In the experiment, a candle is waxed onto a pie tin, then water is poured into the tin. After lighting the candle, it is covered with a glass or a jar. The candle goes out and water rises in the jar. In addition to concluding that the candle needs air to burn, the teacher may likely ask what else this experiment demonstrates. Usually some student estimates the volume of water entering the jar and reports that about one-fifth of the container was filled. This, the class concludes, is due to the fact that about one-fifth of the air consists of oxygen, a fact which they read in the science textbook. If the teacher recalled her high school course in chemistry, she would remember that the carbon dioxide produced would occupy as much space as the oxygen that was burned, so this is not the chief reason for water rising in the jar. (By careful manipulation it has been possible to vary the air fraction in the jar after burning from 5 per cent to 40 per cent of the volume of the jar.) Probably the chief reason for water rising in the jar was the heated and expanded air which cooled after the candle went out and water replaced the air which had escaped. There are numerous other problems involved in this demonstration; how much carbon dioxide is dissolved in water; how much oxygen is combined to form water? The deductions by students and too often the teacher as well are only guesses. Unless the students' conclusions can be checked, little is learned but verbalization of a concept. But in general, teachers prefer the deductive approach to teach science because they maintain they can "cover the material" faster! However, merely exposing students to subject matter certainly doesn't assure that they have learned it. Neither does it have much value if it only consists of memorized statements.

Audio-visual teaching aids. Few elementary teachers are aware or make maximum use of the many science teaching aids available to them. Learning can be stimulated, and teaching can be enriched and made more effective by using appropriate aids.

Most teachers use blackboards, but the display board (commonly called a "bulletin board") is seldom used to enhance science teaching.[3] The new peg boards permit three-dimensional displays and shelves for showing actual specimens. In presenting displays, simple ideas appear to be the most successful. A caption such as "Which of these are machines?" might show a variety of tools, or "Where are the insects on this plant?" could illustrate animal camouflage. Flannel and magnetic boards have been used successfully to develop progressive stages such as life cycles, habitat scenes, and sequences of erosion. They can also be used to show mockup models of machines, and step-by-step development of plant parts or engine operation.

A great variety of new maps and globes are also available. The new plastic physiographic maps are far more meaningful than the flat surface printed maps. Increased emphasis on space travel almost necessitates that each classroom have a globe. Plastic models of insect specimens, and mockup versions of engines, radios, solar systems, skeletons, and rockets in all degrees of complexity are now available. They are very effective in developing some of the fundamental concepts. Pupil-made models of physiographic features may be combined with plastic models as well as other objects for greater effectiveness. This may satisfy the pupil's aesthetic desire and might also serve as an evaluative technique.

Many teachers find film strips more useful than films as teaching aids. The frames may be shown slowly and explained by the teacher. Questions can be discussed while the film strip is in progress. With the availability of small transparency viewers, committees of one to five pupils may watch a film strip while the rest of the class is doing other science research.

The number and quality of science films has increased enormously in the last ten years. Hardly a topic is taught in the grades that doesn't have several films relating to it. City and county visual-aid libraries as well as many private industries and public agencies will lend teachers their films. One of the serious difficulties to using films is the long advance booking date necessary, often six months or more in advance of showing time. In addition, films should be previewed by the teacher before they are shown to students. One other difficulty teachers report with motion pictures is that students usually consider films and television as entertainment. It is important that the film be shown, not as a reward, but as an aid to the study of a science problem. Many science teachers have found value in showing the picture twice, the first time as a preview. Before the rerun is presented, the essential points to be looked for in the film are listed on the board. Following the second film showing a discussion and an evaluation should be made to determine how the presentation aided the science study.[4]

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[3] M. F. Vessel and Herbert Wong, *Science Bulletin Boards* (San Francisco: Fearon Publishing Company, 1962).

Another useful instrument for science visual aids is the opaque projector. Only a moderately darkened room is needed to project non-transparent materials on a screen. Small objects or pictures can often be enlarged for projection. This technique has been used to project maps and diagrams on display and blackboards for more detailed study. Many schools conducting team teaching have found the opaque projector an indispensable visual aid.

Evaluation of Elementary Science

Evaluation is an essential facet of teaching. It is as important as is the setting up of the objectives for a course. Unless a teacher is interested in knowing how well her students are getting along in the study and whether or not they attained the objectives or outcomes she established, she has no idea how effective her teaching has been. Evaluation also enables the teacher to better understand the many related problems of the individual child.

But evaluation involves much more than objective and subjective tests to determine how many facts or principles the student can recall. Since the process of science and the accompanying attitudes, interests, skills, and appreciations are of major importance in science teaching these are the items that should be sought for in the evaluative instruments. But what scale does one use to measure how appreciative or interested one's students are? These intangibles are as difficult to measure as are truthfulness or thriftiness. Over a period of time one can usually note some change; perhaps anecdotal records and tape recordings provide the best evidence that changes in attitudes and skills have or have not occurred.

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[4] The reader may find the following sources useful in obtaining film lists: Encyclopaedia Britannica Films, Inc., Wilmette, Ill.; Film-Strip-of-the-Month Club, New York, N.Y.; Film-strip House, New York, N.Y.; Jam Handy Organization, Detroit, Mich.; Life Film-strips, New York, N.Y.; Society for Visual Education, Inc., Chicago, Ill.; and Young America Film-strips, McGraw-Hill Book Co., Inc., Text Film Department, New York, N.Y.

Two general kinds of evaluations may take place in the elementary grades: teacher evaluation of pupil progress and pupil evaluation of his own progress.

Teacher evaluation of pupil progress

Anecdotal records. In the primary grades anecdotal records are perhaps the principal means of recording the students' change in behavior as a result of science teaching. The following are some items the teacher could look for: What students have shown an interest in the science activities? What students were able to use a variety of sources to find help? Did students question the solutions to the problems? Did they demonstrate ability to think through a proposed experiment? Did they relate answers to previous experiences?

Tape recordings. A series of tapes of class discussions summarizing a project or unit have proved very useful in evaluation. When these tapes are analyzed, progress of individual students in regard to class participation, science interest, creative thinking, and problem solving ability may usually be ascertained.

Paintings, models, songs, and dramatic responses. These activities may show the interest and the depth of perception of a science experience. In primary grades reading and writing skills have not been achieved, hence these activities may represent the sole means of evaluating the students' progress.

Pencil and paper tests. These are of many kinds, including fill in the correct answer, select the correct word that answers the question, identify the specimen, science puzzles, multiple choice answers to a question, and essay questions. Each type of test has some advantages and its value depends upon what objective the teacher is trying to evaluate. There is a distinct advantage to varying the type of test used in order to keep the testing phase of teaching interesting. Generally the tests fall into three categories: (1) to identify the innate ability or intelligence quotient of the individual; (2) to determine the present knowledge or attainment of the student; (3) to diagnose the shortcomings in the student's learning.

Attainment tests are commonly used to determine what knowledge the student has. These tests may be simple true and false tests, fill in or select the correct word, matching items, and situation problems. A fill-in test might include such as the following:

> Write in the correct word or complete the sentence with the correct word:
>
> The element in air needed by all living things is ____________.
> Water freezes if it is cooled to a temperature of ____________ °F.
> The north pole of a bar magnet attracts the ____________ pole of another bar magnet.

One of the better methods for preparing such a test is to write brief factual statements and then omit the essential word. Too often more than one word may satisfy the condition and unless the teacher is aware of such a condition it leads to difficulties. One of the most widely publicized examples of this kind of test shows a diagram of a leaf and a list of words to be matched with the various structures. If the midrib of the leaf was labelled *vein*, this would be an error in terms of the instructions. Furthermore, the leaf stalk or petiole is called a stem which also is not strictly correct. This merely emphasizes the need for having several individuals check the test questions for ambiguity and errors.

A second class of tests might be called "practical examinations." The student may be required to handle equipment or materials in a correct way. Mounted pictures or collections of specimens are placed on a table. The students are asked to group these items. An assortment of animals might be presented with instructions to group them according to: plant eaters, meat eaters, or plant and animal eaters; those having an outside skeleton, and those having an inside skeleton; or grouping the animals into classes of amphibians, reptiles, and so on.

Assorted pieces of copper wire, some having the insulation removed from the ends, a battery, and a doorbell are provided. The student is asked to connect the wires to make the bell ring.

A ten-gallon aquarium filled with water, a four-foot piece of hose, and a pail are provided. How can the aquarium be emptied of water?

The last two examples require personal observation of the teacher to be of greatest value. It is presumed that the teacher has provided the student with similar experiences previous to confronting him with such a problem situation.

A third type of exam might be called a "situational test." For example: A cup of water sweetened with half a teaspoon of sugar is placed on the table alongside another cup which contains a similar solution of salt water. How can you tell which cup contains the sugar without tasting the contents? How would you set up an experiment to find out if grasshoppers locate their food by seeing it or by smelling it? How far out into space must one go to find the gravitational force of the earth equal to the gravitational force of the moon? Although it is difficult to score this kind of test, it measures more than rote memory—it measures the analytical process and the application of facts to a problem situation. If these examinations are properly prepared, the students will find them exciting fun compared to the usual examination. This kind of a test also provides the student practice in writing for it serves as an essay type of examination as well.

Standardized tests. Superintendents will wish to know how their students compare in science achievement with students of other schools. Commercial tests which have been properly analyzed are the best instruments to make such a comparison, but few are available. Standardized tests may also be used by the teacher to measure progress and abilities of students in her classes. Since there seems to be no general agreement as to what should be taught in elementary science, it does not seem possible to develop an examination that will equate students all over the United States. Some standardized tests claim to measure the scientific aptitudes of students as well as their ability to recall subject matter. Such tests are difficult to prepare and difficult to validate. Some, such as the STEP forms, are a move in the right direction.[5] See the *Mental Measurements Yearbook* [6] for further suggestions on testing. The reader is also referred to another book in the Library of Education series by Ahmann.[7]

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[5] *Sequential Tests of Educational Progress: Science,* Cooperative Test Division, Educational Testing Service, Princeton, New Jersey.

[6] *Mental Measurements Yearbook,* Oscar K. Buros, ed. (Highland Park, N.J.: Gryphon Press, 1953).

[7] J. Stanley Ahmann, *Testing Student Achievements and Aptitudes,* Library of Education (Washington, D.C.: The Center for Applied Research in Education, Inc., 1962).

Pupil self-evaluation. Evaluation of his own progress at the completion of an experiment or a science unit has provided the teacher with an excellent insight into the student's science learnings. This also provides the student practice in critical thinking and the analysis of his problems and conclusions. Some teachers encourage class evaluations of pupils' contributions, finding this an excellent teaching device as well as a means of evaluating her own teaching.

It can be seen then that evaluation is a continuous program—not merely an examination at the termination of a unit. The oral evaluation by students of their daily work as well as anecdotal notes by the teacher may be of far more value than a brief written examination at the conclusion of a topic. The teacher should make a constant effort to evaluate the objectives set up for teaching the particular science unit, and not merely assess the fragments of scientific facts and descriptions that may have been learned.

CHAPTER IV

Solving Instructional Problems

The problems concerned with providing an adequate elementary teaching program are numerous. In general, they can be divided into two groups, those concerned with the physical facilities and others concerned with teacher preparation.

Improving Facilities

Science as a part of the elementary school curriculum must fit into the standard elementary classroom. A number of added facilities, however, would make the classroom much more desirable, not only for the science program, but for art and social studies as well.[1]

Classroom facilities. Running water and a sink are essential for most elementary classroom activities as well as for science experimentation. Ample electrical outlets should also be available to provide special lighting and power for hot plates and other electrical devices.

Lighting in the room should be adequate and easily controlled. Shades, draperies, or blinds should be practical and satisfactory for darkening the room when films and slides are shown.

Counter space around the room provides a work surface and a display area, as well as good storage area below.

Bulletin, chart, and peg boards should be available for displaying materials—the latter to permit three-dimensional displays of projects.

Movable tables and desks are very desirable to permit the meeting of small study and work committees. An area should also be reserved for ongoing experiments where some long term projects will not be continually disturbed. A sturdy table or workbench is also desirable.

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[1] Write to Scientific Apparatus Makers Association, 20 North Walker Drive, Chicago 6, Ill., for suggestions on room design and desirable equipment.

Equipment. The lack of equipment for conducting science activities is still considered a major obstacle to science teaching by many elementary teachers. Unfortunately much of this difficulty is a result of their college training. Too many teachers feel that unless they have a Bunsen burner and pyrex glassware they cannot conduct a science experiment. But an electric plate, an alcohol lamp, or a hand-sized propane burner will serve very well for a heat source and a baby bottle will often substitute for the pyrex beaker.

There may be a real disadvantage in using elaborate apparatus in the elementary classroom, cost aside. The student may focus his attention on the complicated equipment rather than the principle being demonstrated. The apparatus may also be too difficult to be operated by the child. Too, there would be little opportunity or incentive to devise or modify equipment around the home that might illustrate the science principle under study.

In most problem-solving experiences the pupils rather than the teacher should decide what equipment and supplies are necessary to perform an experiment. But it usually is the responsibility of the teacher to obtain most of the materials. Inasmuch as this is true, it is far more convenient to have most of the common items on hand than to have to search them out in the community for each experiment.

The following list was prepared during an elementary science workshop for inservice teachers. It could be used as a check list of science items needed by an elementary school although there are many items which the teacher will want to keep in her own room. This list [2] is not intended to be complete, but it does suggest the majority of items one might need.

For convenience, the "shopping list" which follows is arranged into more or less logical areas. Most communities will have shops that can supply most of these items; a few might have to be purchased from scientific supply companies.

ELEMENTARY SCIENCE SHOPPING LIST

Plants and Animals: Animal cages—in terms of animals to be housed; insect cages; white rats, hamsters, or similar animals; aquarium, fishes, and aquatic plants; terrarium; assorted plants, seeds, bulbs, assorted flower pots; sand and fertile soil; soil fertilizer, including nutrient chemical mixtures; microscope, plain but good quality; microscope slides and cover plates; plant press; petri dishes, nutrient agar; slaked lime (for lime water); tincture iodine (for starch test); Benedict's solution (for sugar test); observation colony for ants, termites, bees.

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[2] Robert Stollberg, *Science Shopping List for Elementary Schools,* (San Jose, Calif.: San Jose State College, 1957). Mimeographed.

Force and Weight—Machines and Engines: Bathroom scales; beam balance, calibrated in pounds and ounces and fractions of ounces (5 to 10 pounds capacity is sufficient); spring balances, calibrated in pounds and ounces (in a variety of sizes); assorted lead sinkers; single pulleys, 1½″ in diameter; double pulleys, 1½″ in diameter; sashcord or stout clothesline; assorted mechanical toys; roller skates; Vaseline; engine models (steam, gasoline, etc.); plane, rocket, and satellite models; marbles, ball and roller bearings; toy gyroscope; prism (shaped wooden block for fulcrum).

Air and Weather—Aviation and Space Travel: Aneroid barometer; assorted flying model airplanes; carbon dioxide capsules; Fahrenheit thermometer (0–230 degrees); Centigrade thermometer; bimetallic bar; weather maps; convection box; cobalt chloride (for humidity indicator); vacuum cup ("plumber's friend"); transparent plastic pump models; lamp chimney; hand-operated pressure pump (such as bicycle pump or athletic equipment pump).

Earth and Sky: Inexpensive telescope; ammonium dichromate (for model volcano); rock and mineral samples; assorted balls.

Light and Sound: Convex lenses— focal length (5 cm, 15 cm, 25 cm); magnifying glass; colored cellophane or gelatin; focusing flashlight; assorted mirrors, plane, convex, concave; triangular glass prism, 3″ long; lantern slide cover glasses, 3¼″ × 4″; lantern slide ground glasses, 3¼″ × 4″; 100 watt bulb with socket and lead cord; blueprint paper and/or Ozalid paper; tuning fork (middle C or A); harmonica; toy musical instruments; bells, common; gamut bells; piano wire.

Electricity and Magnetism: Plastic and glass rods, fur and silk (for electrostatics); rubber balloons; radio hookup wire—solid pushback, or bell wire, plastic covered No. 18, 20, or 22. Assorted magnet wire; dry cells, No. 6 size; flashlight (2-cell type); screw-base miniature lamps—1½ volts, 2½ volts, 6 volts; screw-base sockets for miniature lamps—flashlight size; Fahnestock clips—1″; alligator clips, screw-type; flexible test-lead wire; copper strip, 1″ × 4″, zinc strip, 1″ × 4″; telephone transmitter and receiver; telegraph key and sounder; electric doorbell or buzzer—low voltage operation; demonstration electric motor; porcelain knife switches; doorbell type pushbutton switches; electric extension cord; electrolysis apparatus; fixed crystal diode (for crystal radio); radio-type earphones; inexpensive Geiger counter and radioactive samples; Christmas tree cords and lamps; piece of lodestone; pair of bar magnets, 3″ to

6″ long; horseshoe magnet, good quality; fine iron filings stored in salt shaker; magnet compass; assorted steel sewing needles and steel knitting needles; assorted large nails (spikes), and bolts.

Chemistry: Litmus paper, red and blue; table salt; ammonia; sulfur; carbon tetrachloride; hydrochloric acid, 10 percent solution, 50 percent solution; sulfuric acid, 10 percent solution; vinegar; copper sulfate crystals; paraffin; baking soda; table sugar; cobalt chloride (for humidity indicator); sodium bicarbonate; starch (*e.g.* flour or cornstarch); carbon blocks (charcoal), carbon powder (lamp black) magnesium ribbon; magnesium sulfate (epsom salts); zinc metal (mossy zinc); manganese dioxide and potassium chlorate (for preparing oxygen); marble chips (for preparing carbon dioxide); household lye; mercuric oxide; phenolphthalein; sodium silicate (water glass); laundry bleach (*e.g.*, Chlorox).

Sources of Heat—Laboratory "Hardware": Candles; alcohol lamp and fuel (wood alcohol); canned heat; wire gauze (screen), 6″ square; electric hotplate, small; liquified petroleum burner, small workshop model; safety matches; pyrex tubes, ¾″ × 6″ and 1″ × 8″; test tube rack; test tube brush; conical flask, 500 cc; pyrex beakers, 100, 250, 500, and 1000 cc; battery jars, assorted sizes; soft-glass tubing (6 mm in diameter); rubber tubing (to fit 6 mm glass tubing); medicine droppers; forceps—*e.g.*, baby-bottle tongs; metal or plastic funnel, 3″ to 5″ in diameter; graduate cylinder (for measuring liquids); set of measuring spoons and cups; filter paper or paper towels; ring stands; burette clamps; ring clamps, 3″ and 5″; wire gauze; right angle-clamps; iron rod, ½″ diameter, 12″ to 24″ long; rubber stoppers—solid, one-hole, and two-hole in sizes as follows: No. 1 (fits soft-drink bottle), No. 2 (fits ¾″ test tube), No. 7 (fits 500 cc conical flask), No. 8 (fits milk bottle); assorted corks.

Tools: Carbon-dioxide type fire extinguisher; pliers, with cutters; screwdrivers, assorted; knife (not folding) can opener, rotary; tin snips; files—flat, triangular, round, fine, coarse; coping saw, with spare blades; sandpaper, assorted; hacksaw, with spare blades; plane, small; hammer; saw—crosscut, 24″ long; bench vise; paint brushes, assorted; glass cutter; diagonal cutting pliers, 6″ long; brace and a few common size bits; rotary drill and a few common size carbon steel twist drills; ice pick; lubricating oil; single-edge razor blades; wire brush; electric soldering iron, solder and flux.

First Aid: Tannic acid gauze, burn ointment; band-aids; merthiolate; absorbent cotton; sterile gauze; adhesive tape; rubbing alcohol; sterile applicators; tongue depressor blades; boric acid solution; smelling salts; first-aid book.

Miscellaneous: Colored chalk; soda straws; tooth picks; pyrex cooking utensils; teaspoons, tablespoons, knives; aluminum cooking pans;

aluminum foil; thread, string; Cellophane, clear and colored; assorted colors construction paper; scissors; steel wool; moth balls; soap and detergent; ping-pong balls; paper clips; water base paints, assorted; assorted quick-drying lacquer in spray cans; assorted colors, crayons; assorted wood (fruit crates, cigar boxes, and the like); assorted dowel rods, broom sticks; assorted tin cans; assorted flat glass; rubber bands; straight pins; thumb tacks; modeling clay; plaster-of-Paris; yardstick, rulers, tapeline, meter stick; large-mouth glass jars; tumblers and china plates, assorted; milk bottles; soft-drink bottles; quick-drying cement; "White glue"; library paste, paper cement, epoxy cement, paste powder; gummed labels; iron wire (*e.g.,* stove-pipe wire and baling wire, coat hangers); assorted nails, staples, tacks; assorted screws, nuts, bolts; assorted colors ink; screen-wire, hardware cloth; assorted cardboard sheets and tubes; absorbent cotton; wax paper; assorted plastic bags; empty cheese and milk cartons.

Since federal funds have been made available for the purchase of science equipment some schools have been able to obtain more expensive equipment. Some communities purchased all the equipment named on standard lists, but in some instances neither the principal nor the teachers knew for what purpose all the equipment could be used.

Money available under Title III of the National Defense Education Act (NDEA) permitted purchase of equipment from a selected list titled, *Purchase Guide for Programs in Science Mathematics and Modern Foreign Languages.*[3] Three lists are suggested in this guide, a *Basic, Standard,* and an *Advanced* list. The "Basic" list of equipment for elementary science is as follows:

Anemometer; balance, spring, heavy duty; barometer, aneroid; beaker, Griffin, low form; bell, electric; binocular, 4X; boiler, double; buzzer, electric; clamps and tongs; compass, magnetic, 1.5 cm; compass, magnetic, 4.5 cm; electromagnet, horseshoe form; first-aid cabinet, with supplies; flask, Ehrlenmeyer; flask, Florence, flat bottom; globe, terrestrial; hot plate, electric, three-heat single unit; hot plate, single unit; kits; lamp, electric miniature; lenses, demonstration set, magnet, bar—Alnico; magnet, horseshoe—Alnico; magnet, U-shaped; magnifier, reading glass; meter sticks; microscope, elementary; net, insect, collapsible; prism, equilateral, lucite; receptacles for miniature electric lamps; rod, glass; spatula, stainless steel; test tubes, borosilicate; thermometer, centigrade, fahrenheit, combined scale; thermometer, centigrade, $-10°$ to $+110°$; thermometer, large, wall; tools; tubing, glass; tubing, rubber and plastic; volt-ammeter, battery test meter.

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[3] *Purchase Guide for Programs in Science, Mathematics and Modern Foreign Languages,* prepared by Council of Chief State School Officers and Educational Facilities Laboratories, Inc., (Boston: Ginn & Co., 1959).

Few schools have even acquired this basic list of equipment; moreover, until elementary teachers are taught how this equipment should be used in a science program, there will be little need for it.

Science kits are also available in all degrees of complexity. Such kits have the advantage of saving storage space and there is also an economy in the choice of materials. The experiments that can be done are usually included in a manual of instructions. The disadvantage of a science kit is that it includes items relating to physical science, largely, and items of a local biological nature would be missing. It has also been claimed by some teachers that the purchase and collection of individual pieces of equipment is a desirable learning experience for them.

Teachers have also prepared their own science kits. Some are stored in shoe boxes and have been called "concept kits" because they contain just the equipment to do a particular experiment. A number of school districts have set up kits of materials keyed to the activities suggested in their curriculum guide. These kits are available on loan to teachers from the curriculum center.

Much of the equipment needed in the elementary school can be constructed. Simple cages, electric light boards, and weather instruments have all been made by elementary students. Such construction can involve the necessity for reading, measurement, and certain motor abilities, and the end product can then be used in a science activity.

Reference Materials. This consists of collections of natural materials, textbooks, trade books, encyclopedias, free or inexpensive leaflets, and films and film strips.

Reference collections of native materials are of inestimable value in the lower grades. A mounted collection of the common butterflies, moths and other insects; a collection of the common weeds, trees, wild flowers, and rocks can be built up by the students or the teacher and her students. Specimens of amphibians and reptiles may be mounted and preserved in jars. When properly mounted these specimens are more effective than most books to aid in the identification of specimens. This does not imply that naming only is important, but once the name of a specimen is known there is a great amount of information that may be learned about it.

Textbooks provide a common source of information for all the students. They should serve as a readily available source to find answers by reading—but this should not be the sole science reading available.[4] Trade books on various reading levels can provide much more detailed information. A brief list of selected professional books for teachers is given in the Appendix.

Pamphlets from industrial organizations provide comprehensive coverage of a small facet of one topic. The booklets often contain colored illustrations and detailed information about processes that are seldom available in books. If properly filed such fugitive materials provide valuable research materials for the student. The students should also be taught how magazine materials may be filed and indexed for future use. This is an important research skill.

One of the excellent services provided by the National Science Teachers Association is periodic mailing of a packet of selected pamphlets prepared by various industries. These publications have been selected by science teachers as materials which they feel are useful to supplement classroom science topics. This is an argument for teachers who have a science interest to join the national organization. At least each school should hold a membership in the association in order to receive the monthly magazine, as well as the selected list of science publications issued by industrial organizations.[5]

During the past ten years a number of excellent films and film strips have been produced suitable for elementary grades. The danger in using films is the same as that in using radio and television programs. The movie alone is often used as the whole science lesson. As with all teaching aids, the teacher must preview the film, make certain it serves a purpose in the unit or problem being studied, and used as an aid to accomplish a teaching goal.

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[4] Three of the better book lists were issued by the American Association for the Advancement of Science under the authorship of Hilary J. Deason: *Books of the Traveling High School Library*, 1959; *Science Booklist for Children*, 1960; *The Traveling Elementary School Science Library*, 1960. Write to the AAAS, Washington, D.C., for copies.

[5] Write to: National Science Teachers Association, 1201 Sixteenth Street, N.W., Washington 6, D.C.

Most schools have access to city, county or state film libraries. Unfortunately these films must be booked six months to a year ahead; as a result they are often shown to pupils at inappropriate times or merely as a time filler for the science period.

Improving the Training of Teachers

Numerous studies[6] have pointed out the inadequacy of science background in elementary teachers. Teachers themselves suggest the lack of science training as one of their principal difficulties. A survey in 1960 by *The Nation's Schools* recorded the administrators' reports from fifty-two elementary school systems in thirty-six states which had an operating elementary science program.[7] To the question of what are the most persistent problems in elementary science teaching, the answers were teacher insecurity in science, poor preparation, rapid turnover, and the need for continuous inservice education just to keep from sliding back.

It should be noted that not only do the teachers feel their preparations in science have been inadequate but also that there is a need for continuous inservice education in science to keep from falling behind.

Teachers not only lack an adequate background in science, they do not know what a good science program consists of. This situation is even more unfortunate if the administrator and general supervisor upon whom the improvement of the curriculum depends are no better prepared in science than are the teachers.

It is not expected that every elementary teacher should be a science specialist. If she is a good social studies, mathematics, or language teacher, she can more than likely modify some procedures to teach elementary science with success. But the teacher must know what is good science teaching!

A number of methods have been used to provide inservice education in science for elementary teachers and to acquaint the teacher with recommended science teaching techniques.[8]

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[6] A number of these have been elaborated in the next chapter.

[7] John Sternig, "The Elementary Grades in the Nation's Schools," *The Nation's Schools,* Vol. 65, No. 2 (1960), 98.

Visitation is one way of encouraging improvement in science teaching. If the teacher can be relieved of her class for several hours by the administration she can arrange to observe a colleague or a supervisor present a science lesson in which she is interested. When properly planned the observer understands what preceded the lesson and she also discusses with the demonstrator what class activities will take place following the lesson.

Workshops rate high with teachers as a means of inservice education. This is particularly true where all the teachers are from the same school district and the workshop activities explore their particular problems or amplify their curriculum guide. A carefully planned program and sympathetic leadership are most important.

Colleges and universities can also provide workshops that are combinations of science content and proper techniques for presentation. The content should probably emphasize physical science for it is in this area that elementary teachers have the least training. In such programs an effort is made to illustrate problem solving, proper conduct of field trips, careful observation, research techniques, and the conduct of evaluation in science. Adequate funds should be made available to provide some materials for the participants—materials which they may assemble and make use of in their own classrooms.

The National Science Foundation has sponsored a few experimental workshops and some inservice institutes for upgrading the science background of elementary teachers, but the task appears so enormous that other ways must be devised. The national programs are mostly stop-gap measures aiding a few teachers to upgrade their science instruction. There is need for an organized pattern of inservice science study continuing over a period of years if the teacher is to get an adequate background—the flavor and substance of science.

Radio and television as inservice programs have been popular. These are intended to provide teachers with a basic background in the science areas and to assist teachers in keeping up with the newer developments of science. Classroom demonstrations can be shown to large audiences to provide a common experience. Presentations to implement the curriculum guide and motivate the teachers have been successful in some schools. More than likely television will become more and more important as an inservice tool.

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[8] See Herbert Wong, *Elementary Science In-service Education Techniques in Selected Public School Systems in California,* doctoral dissertation, University of California, Berkeley, 1962.

Curriculum study. Preparation of science curricula involves research, planning, and testing. Teachers participating in such committee work become acquainted with the science materials available and learn how these materials are organized in other communities. Many administrators feel that the major value of curriculum committees is the inservice science experiences that such research provides.

Conferences and conventions provide teachers opportunities to meet the leaders in science teaching and see the new books and equipment available for improving science education. Conference programs may provide teaching demonstrations at various grade levels and, frequently, common teaching problems are openly discussed by expert teachers.

Science consultants and supervisors are also employed in some districts to coordinate the science program from kindergarten through the high school grades. In view of the importance of science, the need for a science consultant is probably as great as is the need for an art or music consultant. The science consultant may also supervise science workshops for the teachers, direct the curriculum study programs and coordinate the requests for scientific equipment.

Junior museums and youth science institutes. In many localities schools or communities have established junior museums or institutes to encourage students with science interests. Facilities may be provided so that projects may be carried on in either the biological or the physical sciences. In some instances studies are continued through the summer months.

Museum staff members often present classroom lessons and provide materials to continue the study. Some museums have established animal lending privileges wherein a student may borrow a rabbit or hamster for a weekend. This new concept of a museum has been a very valuable adjunct to inservice teacher education.

CHAPTER V

Recent Developments and Trends to Improve Elementary Science

Curriculum Structure

With the tremendous developments in science, it is apparent that school time does not permit coverage of all old and new science topics. A gradual but continuous process of "handing down" science subject matter from high schools to elementary schools has been taking place. Much of the ninth grade general science taught 30 years ago may now be studied by students before they reach the seventh grade. Thus planning and revising curricula for elementary science continues to be of major importance.

An outstanding recent study of elementary science in the country was made in 1961 by the American Association for the Advancement of Science (AAAS) aided by a grant from the National Science Foundation. Three regional conferences were held in St. Louis, Missouri; Berkeley, California; and Washington, D.C. At the conferences, leading scientists from the various disciplines met with administrators, elementary teachers, psychologists, and science educators to propose a program to improve elementary and junior high science. The summary points of agreement were published in the journal *Science*.[1] Because of the anticipated impact of this study on future elementary science programs, the salient points of agreement of the composite meetings are listed:

> 1. *Science should be a basic part of general education for students at the elementary and junior high school levels.* During these early years children form their basic attitudes, patterns of thinking, and modes of behavior. It is therefore during these years that particular attention must be given to establishing the attitudes and modes of inquiry that are associated with the scientific enterprise—

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[1] American Association for Advancement in Science, "Teaching in Elementary and Junior High Schools," *Science*, Vol. 133, 3469: 2019-24.

its process and content. Whatever the school does, children are inevitably exposed to "science" and technology through all forms of mass communication; but they can acquire understanding of these powerful forces only through an orderly intellectual experience in the study of science. This orderly intellectual experience is the responsibility of the school.

2. *Instruction at the elementary levels should deal in an organized way with science as a whole.* The instruction is not to be diluted chemistry, biology, or physics, but should consist of strong blocks of knowledge which cut across traditional science disciplines. Some of the concept areas suggested were: cosmology, evolution, ecology, structure and function, reproduction and development, structure of matter, energy relationships, and changes of state of matter.

3. *There must be a clear progression in the study of science from grade to grade.* Science instruction at the elementary and junior high school levels should be planned and coordinated as a ten-year sequence, beginning with kindergarten and continuing through grade 9.

4. *There should be no single, national curriculum in science.* This judgment was based partly on philosophical objections to central dictation of curricular planning, and partly on recognition that alternative choices of subject matter and order of progression might be equally effective.

5. *Science teaching should stress the spirit of discovery characteristic of science itself.*

In another study a conference of elementary science leaders and administrators suggested recommendations for strengthening the elementary science programs.[2] The need for structuring the science curriculum was demonstrated. In order to improve teaching, it was suggested that the first step should be a careful inventory of school facilities. This would include an accounting of materials, apparatus, time, staff, and available community resources. From this point the school staff could proceed to develop a curriculum guide. Blough says, "Since the most successful curriculum guides are built to fit the needs of those who will use them, it seems important to involve as many teachers as possible in this preparation. . . ."[3] The report emphasizes that the use of the guide will be most effective when it is specific enough to be helpful, presents a variety of possibilities, is flexible, and permits for originality of those who use it.

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[2] Glenn O. Blough, *It's Time for Better Elementary School Science* (Washington, D.C.: National Science Teachers Association, 1958).

[3] *Ibid.*

Grade placement of subject matter. Attempts to "grade-place" subject matter have been quite inconclusive. Science educators can arrange a series of concepts in order of increasing difficulty, but no one really knows whether or not a concept belongs in third grade or sixth grade. It would seem that logically if individuals differ in mental ability and vary in their background of experiences, they must vary in readiness to understand science concepts. Furthermore, the rapid dissemination of new scientific information by television and publications changes the background of experiences and increases the sophistication of students making grade placement a very temporary arrangement.

Two major possibilities for arranging the science subject matter are found in practice. One is to teach a few concepts in each of the basic science areas each year. This would mean a very sketchy treatment of all topics which certainly isn't satisfactory. The other possibility is to arrange a spiral type of program permitting a topic to be studied again every second or third year. The AAAS Committee study recommends that the sequence of science units be arranged in three-grade-range blocks and the selection of the units used would be determined by the teachers at these grade levels in a district.

Selection of subject matter. With the vast array of subject matter available, one of the chief problems has been to determine what is suitable for use in the elementary grades. At present, the concern of many scientists is that the methods of inquiry and the process of science are more important than descriptive science.

Some questions have been raised regarding the organization of a science curriculum based upon subject matter content. Watson[4] asks, "How does one know what is meant to be learned, whether it has been learned, or what significance it will have conceptually and philosophically if we have a topic like rocks, or magnets, or insects?" He continues, that if science is examined as an intellectual operation, and we are concerned with "how we know" as well as

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[4] Fletcher Watson, "New Approaches to Science in Elementary Schools," *Science and Mathematics: Countdown for Elementary Schools,* Symposium (Oklahoma City, Okla.: Frontiers of Science Foundation of Oklahoma, Inc., 1960).

"what we know" it is possible to select some major themes which distinguish science from other intellectual pursuits. Four of the twelve examples of themes of science suggested by Watson are listed to clarify his idea:

> 1. Science is a process, or operation, by which man attempts to establish patterns describing the world.
> 2. Man seeks an orderly world to permit him to anticipate or predict future events.
> 3. In our efforts to describe the world, we use imaginary or ideal attributes that appear imperfectly in many specific instances.
> 4. We seek to know what happens if naturally occurring conditions are changed somewhat—this leads to exploratory observation and experimentation.

Thus Watson feels that it isn't the subject matter that is important, but how this content is presented to the pupils.

Heathers[5] also suggests that the elementary science sequence be process-centered. If process is the key word in science, Heathers suggests three categories: (1) the *process of inquiry* commonly called scientific method; (2) *processes in nature* discovered through using the scientific method—these are the cause and effect relationships; (3) *process of applying knowledge*—the technological aspects of science.

Continuing, Heathers says that while the course of study can be based on content it can also be based on levels of science sophistication. The first level of development would be likened to the "language of science." In this stage, stress would be placed on learning the "scientific method" of thinking. The second phase would teach terms and procedures necessary for planning and conducting simple experiments. But from here on Heathers does not propose further phases of development, stating that it would be difficult to do so in view of the gaps in our knowledge about child development and learning.

In elaborating on the spiral development of a science sequence, Mallison suggests a somewhat similar idea.[6] She says the approach used to introduce science at the K–2 grade level should be largely *descriptive;* it should be concerned with a study of the characteristics of objects. In the grades 3–4 the curiosity of children seems to be concerned with the relationship between themselves and their environment. Emphasis in science should be on *utilization*—the "use and value" aspects of science. In the upper grades—grades 5–6, the child is concerned with "what makes it go," "what makes it work," "what caused it to happen." Here, the *operational* or *functional* approaches to science should be used.

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[5] Glen Heathers, "A Process Centered Elementary Science Sequence," *Science Education,* Vol. 45, No. 3 (1961), 201-206.

[6] Jacqueline V. Mallison, "The Current Status of Science Education in Elementary Schools." *School Science and Mathematics,* Vol. 61, No. 4 (April, 1961), 252-70.

It is apparent from these studies that the major concern is over the *manner* in which science subject matter is presented to the students and that subject matter is largely a *vehicle* for the learning experience, not an end in itself. Research and experience have shown that the teacher achieves the objectives for which she teaches; one cannot achieve an attitude of critical thinking and withholding judgment if the students are largely memorizing scientific names.

Brandwein,[7] in an excellent article on elementary science, has suggested six conceptual schemes around which the total science program should be structured. A year long study by a selected science curriculum group[8] proposed a science program structured around four pervasive themes: (1) All objects are made of matter and although this matter can be changed, it cannot be created or destroyed by ordinary means. (2) All activity living or non-living involves forces called *energy*. Under ordinary conditions this energy can change form but it cannot be created or be destroyed. (3) There is a continuous interaction of energy and matter (or of materials), both living and non-living. (4) All materials of the universe and the organisms found on the earth experience an evolutionary process or a change with time.

The concepts involved with these themes are arranged in such a way that they enable the teacher to see how the concept she is developing serves as a foundation for the broader generalizations developed in the later grades.

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[7] Joseph J. Schwab and Paul F. Brandwein, *The Teaching of Science* (Cambridge, Mass.: Harvard University Press, 1962), p. 133-36.

[8] Santa Clara County Science Curriculum Report, 1962. Write to Dr. Myron Schussman, Director, County Office Building, San Jose, Calif.

Techniques of teaching science. Numerous attempts have been made to determine the best technique for teaching elementary science. The "problem solving approach" has been compared with textbook discussion techniques by Carpenter in teaching two topics: Magnets and Adaptations of Animals.[9] He reported that greater gains were made by those who had been exposed to the problem solving approach and that the personal preference of the students was for this method of teaching rather than of reading and discussion. Hubbel [10] compared the teaching of three groups of eighth grade students using (1) the textbook method; (2) the audio-visual method using filmstrips; and (3) the pupil-activity approach. He found that the pupil ranking in achievement was just the reverse of the order listed; that is, the group which used the pupil-activity approach scored highest and those using the textbook method scored the lowest. Recent studies made in Minnesota [11] and Kentucky [12] have showed that textbook reading and discussion represent the most-used science teaching methods. The committee report of the AAAS states that "teachers should employ the experimental approach to science with emphasis on inductive learning."

There seems to be no clear cut preferential way to teach science on the basis of preliminary research studies. In general, standardized instruments of measurement are not adequate to measure the science objectives we hope to obtain. Some individuals have suggested that the value of one method of teaching over another may only be reliably discerned after several years of time have elapsed instead of testing immediately following the experiment. Long term studies should be planned to examine this hypothesis. Perhaps Barnard best sums up the question of teaching methods as he writes: [13]

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[9] Regan Carpenter, "A Study of the Effectiveness of the Problem Solving Method and the Textbook-Discussion Method in Elementary Science Instruction." Unpublished doctoral dissertation, University of Colorado, 1958.

[10] Lawrence Hubbel, "An Investgation in the Use of the Filmstrip Method, the Pupil Activity Method, and the Textbook Method in Presenting Science Concepts to Eighth Grade Pupils." Unpublished doctoral dissertation, Northwestern University, 1947.

[11] Jane Johnston, "Achievement in Elementary School Science in a Representative Sampling of Minnesota Schools," *Science Education*, 45 (February, 1961), 58-61.

[12] Howard D. Lusk, "An Investigation of Science Education in Selected Kentucky Public Elementary Schools," *Bulletin of Bureau of School Science*, 31, No. 4 (June, 1959).

[13] J. Darrel Barnard, "Science Teaching Objectives and Methods," *The Science Teacher*, Vol. 26, No. 2 (March, 1959), p. 111.

There is no one method of teaching science, nor is there a method that will be equally effective for any one teacher in all teaching situations. The beginning teacher, who assumes that during his first few years of teaching science he will develop an organization and a method that will serve him well for the remainder of his professional career, is doomed to disappointment. Science is dynamic. Students change from class to class and from year to year. The science teacher himself is undergoing change. It is inevitable that his techniques of working with young people must frequently be evaluated and modified in ways to make his teaching more effective.

Outcomes for teaching elementary science. Whatever the methods of teaching, the following outcomes were proposed for sixth grade students as a result of their elementary science experiences. These were compiled by a national committee of secondary science teachers. The student after completing the sixth grade should exhibit: [14]

1. A *"curiosity and enthusiasm"* for science and things about him.
2. He should have developed *"habits of systematic observation"* and be able to organize and classify objects.
3. He should have a *"start on quantitative thinking and representation."* This would apply his arithmetic skills and give him practice in graphing such things as sequences in time and space, weight and age, and population figures versus the number of generations.
4. He should have some *"familiarity with modes of scientific thought."* This can only be attained through experiences in problem solving and scientific thinking.
5. He should have a *"knowledge of the development of science."* This is not for the purpose of learning more history but to appreciate the social conditions and the thinking and strategy employed by earlier scientists.
6. He should have developed the *"beginnings of a scientific vocabulary."*
7. He should have developed a *"desire for scientific explanation."* The student should have the ability to think through and see causal relationships and be aware that this kind of thinking may often provide satisfying explanations.

Experimental projects. The national Science Foundation is sponsoring a number of exploratory programs in elementary science.

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[14] *Planning for Excellence in High School Science* (Washington, D.C.: National Science Teachers Association, 1961), p. 36.

These may offer new insights into the capacity of children to understand science concepts which until now have been considered only suitable for students of the secondary grades.

At the University of Illinois, Wyatt and Atkin are developing an elementary school science project with emphasis on astronomy. Some of the major themes selected are measurement of length and distance, the physical force of gravitation, nature of a star, life story of stars, structure of the galaxy and the universe of galaxies and cosmology. When this book was written, two of three elementary astronomy books and tests for students and guide books for teachers with tests had been planned and completed. These books or units are now being tested in more than 250 classrooms throughout the country.

At the University of California, two projects are underway concerned with improving elementary school science. The larger project is at present directed by Diliberto of the mathematics department, there. In an effort to improve the science content and demonstrate more clearly what the methods and goals of basic science are, the cooperating scientists are preparing experimental teaching units in areas of their own speciality. These units are tried out in neighboring schools by the regular classroom teachers. Five units have been tested once and revised. The topics of these units are coordinates, force, human physiology, embryology, natural selection, and structure and properties of matter.

The second University of California project is headed by Karplus of the Lawrence Radiation Laboratory. Karplus was the instigator of the larger California project, but he felt the need for a different emphasis to improve elementary science instruction.

Two problems with which his project is concerned are scientific literacy and the science conceptual framework. To establish scientific literacy, Karplus maintains we should teach the meaning and importance of current scientific concepts and their interrelationships to all students in school. Teaching solely for developing the "spirit of scientific inquiry" is very difficult because the student arrives at school with an already well established "natural philosophy" or system of preconceptions regarding words and their meanings.

Karplus is testing his program by teaching it himself in the elementary grades of the Berkwood School in Berkeley. He begins his study by introducing the concept of a "system." "A system is any collection of objects in which one is interested." This is the definition children learn. Once the system has been defined one can ask whether or not the objects in the system are doing anything to each other, that is, interacting. Direct interaction, such as floor-and-table, is contrasted with distant interaction, such as two boys pulling on a rope. An additional teaching device used is a stick-puppet called "Mr. O," the observer. Each child has a puppet and uses it to interpret the relative position of things by describing how "Mr. O" sees these phenomena.

> The outline of Karplus' twelve-week course shows how the children are led (with the help of "Mr. O") from the simple concept of a system to some fairly complicated ramifications of modern science. In week 4 for example, the children are considering the motion of objects as seen from different reference frames. In week 8, they are comparing systems in equilibrium with transient phenomena, and are determining how interactions of objects in a system cause "happenings." Later, the class learns that there are interactions to which special names are given, such as electric, magnetic, chemical, gravitational, and elastic.[15]

Private organizations such as the Ford Foundation and the Science Manpower Project are also involved in programs to improve science teaching.

Preliminary results from all of these projects are sufficiently encouraging and exciting to warrant further study of these programs and a careful evaluation of the reported findings. A summary of most of the projects in operation at the time of this writing is given in the references below.[16]

Departmentalization. In some school systems an attempt has been made to departmentalize subject matter even as low as the fourth grade. Some schools departmentalize for only half a day to teach the mathematics, science, and English. A pilot study sponsored by the AAAS has been conducted to determine the effectiveness of specialists to teach fifth and sixth grade mathematics and science.[17] Gibb and Matala reported on this study which was carried on in four different school systems (Washington, D.C.; Versailles, Kentucky; Lansing, Michigan; and Cedar Falls, Iowa). Four classes of fifth graders and four classes of six graders with matched economic and social background were selected from each district. Two of the four classes were taught by the classroom teacher, the other two classes by a specialist in science and mathematics. Tests were administered at the start as well as at the end of the school year.

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[15] "An Experiment in Science Teaching," *The Magnet*, Radiation Laboratory, University of California, Berkeley, Calf.. Vol. 6., No. 5 (May, 1962).

[16] American Association for Advancement of Science, *Science Education News*, "Report on Broad Improvement in Science Education" (Washington, D.C.: USGPO 1961); and *The School Review*, University of Chicago Press, Chicago, Ill., Vol. 70, No. 1 (Spring, 1962).

Tentative conclusions drawn up at the end of the first year of the experiment were interesting:

At the sixth grade level the special teachers were more effective than the teacher in the self-contained classroom. However, the fifth grade classes with a special teacher did no better in science than the regular classroom teacher.

In rural or urban school systems, there was no evidence that one method was superior to the other.

The interest of students in the subject matter could not be shown to be consistently greater by either system of teaching.

Whether or not the elementary child benefits more by being taught by a science teacher than a teacher in a self-contained classroom is not known; more research is needed. With the pressure of numbers of students and the interest in team teaching, it appears certain that more changes in the direction of special teachers will occur.

Gifted science students. The gifted science student is also receiving more study.[18] The chief difficulty has been to identify the gifted student. Some of the criteria frequently mentioned as characteristics of the brilliant student are listed below, but at the present time no one test evaluates all of these items. The gifted student usually exhibits:

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[17] *Study on the Use of Special Teachers of Science and Mathematics in Grades 5 and 6,* Science Teaching Improvement Program, American Association for the Advancement of Science (Washington, D.C.: USGPO, n.d.), pp. 1-5.

[18] *Education for the Talented in Mathematics and Science,* U.S. Department of Health, Education, and Welfare, Bulletin 1952, No. 15 (Washington, D.C.: Government Printing Office, 1953); and Paul F. Brandwein, *The Gifted Student as Future Scientist* (New York: Harcourt, Brace and World, Inc., 1955).

1. An IQ of 120 or higher.
2. An exceptional memory for details. For example, the fourth grader who knew the cube roots of the numbers from one to ten to eight decimal places in some instances.
3. The ability to visualize abstractions and to carry on abstract reasoning. Usually the student suggests hypotheses based on the data and is quick to detect probable discrepancies.
4. An insatiable curiosity to learn more about things in which the ordinary student has little or no interest.
5. A determination and persistence to complete a particular task. A fifth grader insisted on checking the effect of alcohol at all degrees of dilution on the freezing point of water.

A conference in 1958 to discuss the talented science student summarized suggestions for course work which might be offered to the talented student as well as methods of presenting the work and the selection of teachers to work with gifted students.[19]

Television teaching. The use of radio and television to supplement science teaching was briefly mentioned in Chapter Three. However, the potential use of television for aiding science instruction seems tremendous. Privately owned stations are setting aside more time for instructional programs and some are also soliciting sponsors to promote good science presentations. Programs such as those prepared by the Bell Telephone Company set a high standard of achievement both in interest and in apparent educational value. More channels will be available for presenting additional programs.

More and more schools are installing closed circuit television. Many larger school districts are installing wiring in all their new schools for future television operations. Programs presented on closed circuit provide an opportunity for more uniformity in basic instruction throughout the school or the school district. One can visualize a television program describing the physiography of the local area. Most of the pupils would be required to watch such a program and from this presentation the grade teacher would attempt to develop those understandings appropriate to the maturity of her pupils.

When teachers experimenting with television in New York City were asked to evaluate the effectiveness of telecasts presented to children in grades K–4, the findings were all favorable.[20] Pupils became more aware of their environment, their interest was high, and they gained an extensive fund of science information.

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[19] *Science for the Academically Talented Student* (Washington, D.C.: National Education Association, 1959).

In 1961, the Midwest Project on Airborne Television Instruction (MPATI) which covers a seven-state area began presentation of a series of elementary science programs to thousands of pupils. Telecasting was done from a flying airplane.

Schram has summarized the findings of approximately 400 instructional television projects.[21] The following are only three of the conclusions that are drawn:

> 1. Television teaching is as effective as the ordinary classroom teaching judging from the results measured by standardized tests.
> 2. Teaching by television seems to have been most effective in the elementary grades, less so in high school, and not significantly more effective than regular classroom instruction at the college level.
> 3. Mathematics and science appear to have been taught more effectively to children by television than have social studies or literature. (Here the expository and demonstration type of class presentation is adapted to television whereas courses such as reading and writing are more difficult to illustrate by cameras.)

It should be remembered, however, that science teaching is not merely demonstrating and talking about science. The evaluation of television in itself is an indictment of the kind of science teaching that is generally taking place in our public schools. Significantly, Schram writes that "a group of students taught by the discussion group method scored higher on a test of problem-solving than did a comparable group taught by television." Gardner, writing about the goals in education, predicts the future of television. He says:

> By 1970 every school in the nation should be equipped for instruction by television; and the advantages and limitations of educational television should be universally understood. Properly used, television could bring superb lectures and other presentations to

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[20] William B. Reiner, "The Effectiveness of a Television Series in Improving Kindergarten to Grade Two Science Teaching Programs," *School Science and Mathematics*, 59: (May, 1959), 397-408.

[21] Wilbur Schram, *What We Know About Teaching from Instructional Television* (Redwood City, Calif., Bay Region Instructional Television Education, 1961), 35 pp., mimeographed.

> school children throughout the nation. For example, demonstrations of scientific experiments of a quality that no single school in the nation can now afford, could be available to every school by 1970. But the role of the teacher will remain secure. Television has notable limitations as a teaching device. There will always be some aspects of teaching that can be accomplished *only* in face-to-face interaction between teacher and pupil.[22]

Closed circuit television will undoubtedly expand and affect most community schools. Although the initial cost seems prohibitive it may not be so great over a period of years. Instead of purchasing twenty slides, specimens, or pieces of equipment it may be possible in many instances to purchase but one, and that item can be viewed by all students on the television screen. Also, movies, slides, pictures, and all other realia may be projected by the television camera. A further argument for television is that it is up-to-date and subject matter not yet in books and on films can be presented. One has little interest in reading about plans to land on the moon in textbooks if such a mission has already been accomplished.

One problem consistently raised by teachers in regard to the use of most television series is how do we use the television presentation in our science program? Unless careful plans have been drawn to indicate where and how the television presentation fits into the curriculum, the presentation becomes a program of entertainment and usually poor entertainment, for amateurs cannot compete with the professional television cowboys and cartoons which are usually witnessed by children.

Programmed teaching and self-teaching devices. Self instruction is one of the latest techniques to be taken up by the schools. Subject matter is structured or programmed and may then be used as a pencil and paper type of activity and incorporated into a book or a machine. Teaching devices are being produced in all degrees of complexity, from a simple mechanical gadget to complex electronic models.

Two general patterns of programmed instruction are commonly used, a linear and a branching arrangement. The linear pattern con-

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[22] John W. Gardner, "National Goals in Education," *Goals for Americans.* Report of President's Commission on National Goals, The American Assembly, Columbia University, published by Prentice-Hall, Inc., Englewood Cliffs, N.J., 1960, p. 89.

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ceived by B. F. Skinner suggests learning in short steps so that the student will more than likely get the right answer. The fragments of information are arranged like the links of a chain.

The branching pattern of programmed instruction has been developed by N. Crowder. It allows for alternate tracks which may or may not lead to the correct answer. Because of the nature of scientific investigations—the numerous pathways, dead ends, and inconclusive results obtained in seeking a discovery, it appears that the branching pattern is better suited to programmed learning in science.

With the increasing concern for attention to individual differences in pupils, the teaching machine or programmed courses should naturally arouse much interest for here is a machine or a self-learning book that can serve as a tutor. Although these devices are not entirely new, they have been much improved. This, coupled with factors such as the shortage of teachers, the explosion in scientific knowledge, and the availability of funds to purchase such equipment has lead to a manufacturers boom in the production of teaching machines. More than a hundred different machines and a great variety of programmed courses were available at the time of this writing.

There are unique features in many teaching machines which make them most effective devices for teaching certain kinds of information. Perhaps the most important aspect is that the programmed lessons utilize an accepted principle of learning; namely, reinforcement of responses to stimuli. Subject matter is organized into small sequential segments. As each segment is performed the students' progress is recorded and the learning may then be reinforced by several similar examples. In a way, the machine acts rather like a skillful tutor, correcting the students' errors and reinforcing his correct responses. The teaching machine also offers the advantage of permitting learning to proceed at one's own speed, serving the slow as well as the faster student.

Programmed learning in science can clarify some of the more difficult concepts by allowing the pupil to discover the information by himself. Some forms of programmed instruction are not too unlike the "keys" to plants and animals which biologists have been using for years quite successfully. Fundamentals of radio, television, and machine operation as applications of science have been effectively programmed by industries and are now being introduced to schools and homes.

Many teachers are preparing their own materials for programmed instruction. It is a slow, tedious task but it offers an insight into how children learn and thus is a valuable teacher-growth experience. In planning a programmed lesson the teacher generally should keep in mind the following steps:

1. Break the topic into small fragments and arrange them in a logical or psychological sequence.
2. Provide cues so that the student is led to discover each bit of information. Make the steps small enough so that he isn't too likely to make mistakes.
3. Possible wrong answers should be considered, but the mistakes should be easily discovered by the students and quickly corrected.
4. Correct answers should be immediately reinforced by another similar problem or experience.

Programmed teaching can be used effectively as an inservice technique for teachers. In an attempt to provide science background as well as some methodology in a limited period of time, programmed lessons have been used with some classes of inservice teachers with limited science experience. The lessons have proved highly popular and seemingly stimulated much interest in the subject matter. The activities provided individual experimentation, inductive and deductive reasoning, setting up hypotheses, and selecting tentative conclusions. The sample lesson outline on static electricity which follows also illustrates how the branching technique is used.

SELF REVIEW OF STATIC ELECTRICITY[23]

To the student—

Important: This is a programmed exercise. This means that you do not go through the steps in consecutive numbers, but you answer questions or draw conclusions at the end of each step and then go to the next step indicated. Unless you follow instructions you will get hopelessly lost.

Before you begin you must construct a test instrument. The materials needed are as follows:

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[23] Prepared by Robert Hassur, Assistant Professor, San Jose State College, San Jose, Calif., 1961.

1 kernel of puffed rice
1 4-inch length of fine silk thread
1 spot of plastic cement (airplane glue)

Attach the puffed rice to one end of the silk thread with cement and the instrument is constructed. It is called a pith ball or charge detector. In all cases be sure the pith ball is neutral before making a test. This is accomplished by touching the ball with your fingers momentarily.

Now proceed with step one—Good luck!

1. Rub the objects listed in column A with each of the objects in column B. Detect a charge by bringing the object near to your neutral pith ball. If the pith ball is attracted the object is charged. (Be sure and test both item A and B for a charge in each case.)

A	*B*
rubber rod	wool
plastic rod	fur
tin can	cotton
sheet of plastic	silk
sheet of glass	
pencil	
nail	

On the basis of your observations or previous knowledge, select the correct answer.

A. All objects can be charged by rubbing with another object—go to 4.
B. Some objects can be charged when rubbed with certain materials—go to 3.
C. Only non-conductors can be charged in this way—go to 5.

2. How did you get here? You did not receive instructions to go to this step so return to #1 and follow directions, please.

3. You found that only certain combinations of objects would show a charge when rubbed. Select a combination that produced the strongest charge, and use it as a control in the following exercise.

Suspend, using tape and silk thread, those objects that showed no charge. Place them one at a time near the pith ball tester, and, at the same time, charge the control object and bring it near the suspended object. Note the results. Next actually touch the suspended objects with the charged control object, and again note the results.

On the basis of your observation select the most correct conclusion:

A. Objects that cannot normally be charged by rubbing can be charged by being near or being touched by a charged object. ____________ 6.

B. Only metallic objects can be charged by being near or by being touched by a charged object. ____________ 7.

C. All objects are electrical by nature, but some conduct charges better than others. A charge can be detected on these objects only if it is continuously applied by an outside source. ____________ 5.

4. Are you sure? Better go back to #1 and try again. Be sure that the pith ball is neutral to start with and is actually moved or attracted by the object to be tested. The object should not touch the pith ball.

5. You have a good understanding of static charges and what causes them so let's review for a moment.

We found that all objects can be electrified or charged in one of three ways:

1. by rubbing with another object
2. by being near a charged object
3. by being touched by a charged object

(True, we tested only a few objects but all scientific generalizations are based on the evidence at hand since no one can test every object or phenomenon in nature. However, feel free to test further if you like.)

We can, therefore, say that all objects contain the ingredients necessary for an electrical charge. Do you know what the ingredients are? Go to #8.

6. True, you have made very careful observations and in a few moments have come to a conclusion that took scientists hundreds of years to arrive at. Now go to #5.

7. Better try again. This time be sure the pith ball is neutral. (Touch it with you fingers.) Go back to #3.

8. Neutralize the pith ball (by touching it with your fingers), and charge it using the rubber rod rubbed with fur. Let the pith ball cling for a moment or until it falls away from the rod. Now charge the rod again and note the reaction of the pith ball.

Next charge a rubber rod and suspend it using tape and silk thread. Bring another charged rubber rod near it. (A plastic rod rubbed with fur will work also.) Note the reaction of the suspended rod.

What conclusions can you draw from this?

A. The pith ball after being attracted took on the same charge as the rod and was then repelled. ____________ 11.

B. Unlike charges attract and like charges repel. ____________ 10.

C. The pith ball kept being attracted to the freshly charged

rod, but the two charged rubber rods repelled each other.
_____________ 9.

9. Your observations and conclusions are correct. Actually, the pith ball was losing its charge between chargings of the rubber rod. For that reason it was continually being attracted. The humidity in the room is probably too high, and the charge is being lost to the air or through the silk thread. However, the tremendous charges of the rubber rods did demonstrate what we were looking for. Go back and read choice #8A.

10. Oh, oh, you are jumping to conclusions. The experiment includes only *one* charge (rubber-fur charge) and one *neutral* pith ball. How could you get unlike charges out of that? Go back to #8 and try again.

11. This is the same conclusion that Ben Franklin came to when he performed the same experiment. He concluded that when the neutral pith ball was brought near the charged rubber rod there was something within the ball that compelled it to move toward the rod. He theorized that if something is neutral, it is 0, and if it is charged it contains something in addition to 0, but the charge is usually obtained by rubbing with another neutral object which is also 0. (A zero rod which is rubbed by a 0 fur = what? 0?) That did not satisfy his problem. He pondered further that there could be two opposing factors in every substance, so that when they are present in equal amounts the result is neutrality. But if one of the factors is in abundance then the object is charged. For convenience' sake he called the opposing factors + and −. Even today we speak of plus and minus charges. Do Ben Franklin's + and − charges satisfactorily explain the action of the two charged rubber rods?

Conclusions:

A. It was the plus factor of the neutral pith ball that was attracted to the rubber rod (assuming that the rubber rod was negative).
_____________ 12.

B. Since we don't know what charge the rubber rod had all we can say is that the opposing charge in the neutral pith ball was attracted to the rod, keeping in mind that the two charged rods repelled each other. _____________ 13.

12. Your assumption is correct, and your answer is correct. The rubber rod does become negatively charged when rubbed with wool or fur. Atomic theory explains that electrons moving about in orbits around a nucleus are actually negative charges. These negative electrons are balanced by an equal number of positive protons in the nucleus of a neutral atom. The electrons are easily lost or transferred (by rubbing or other means), and in certain materials (non-conductors or insulators) they can build up in surprising quantities producing a negative charge. In some materials, however, the electrons are conducted away as fast as

they are being transferred so no build-up or charge occurs. Such materials are called conductors. Which of the materials that you have handled thus far were conductors? Which were non-conductors? If the rubber rod is charged negatively after rubbing with cat fur is the fur also charged? Is it the same charge as the rod?

13. You're a cautious one. It is a good idea not to make flat assumptions in drawing a conclusion. Your keen observations have led you to the correct answer. Now go to #12 for a discussion.

Other programmed lessons on magnetism, machines, and biological classification have also been developed which show some promise.

Whereas television may tend to standardize teaching these self-teaching devices permit more individualized instruction. However, a creative insight shown by a youngster solving a science problem cannot be detected by the teaching machine; only an alert and sympathetic teacher can capitalize on such a situation.

Teacher Education

The elementary science program depends ultimately on the teacher; if she has the knowledge, interest, and ability, a good science program will be developed. Improvement in teacher education must occur in both the preservice and inservice programs.

Preservice programs. An elementary teacher should have a clear understanding of the subjects which she teaches as well as a knowledge of child psychology. In a four-year program this is a large order for a prospective teacher and she usually falls short of achieving such a goal. Richardson[24] and others in discussing the preparation of elementary teachers for competence in science have suggested the need for science content and an understanding of the social impact of science, as well as an understanding of the scientific outlook and the breadth of scientific inquiry. There should be an opportunity for teachers to analyze science teaching problems in college classes as well as back home in their school. The prospective teacher should have experience in utilizing and adapting local resources and conducting direct investigations in the laboratories and in the field. Course work in science beyond that required for the general education of all teachers is necessary and a course in science for children is essential.

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[24] John S. Richardson, *et al.*, "The Education of the Science Teacher," in *Rethinking Science Education* (Chicago, Ill.: University of Chicago Press, 1960), pp. 258-60.

California has recently legislated that all elementary teachers must have an academic major and five years of college education to qualify for an elementary teaching credential. It is hoped that this may allow time for more course work in science.

What college courses should the elementary teacher have to enable him to teach elementary science in the self-contained classroom? A state advisory committee on elementary science in California suggested these minimum recommendations.

A one-year basic course in the biological sciences and another year course in the physical sciences both of which involve laboratory experiences to accompany them.

A combination methods and materials course in which the student will obtain experience in organizing science activities for children, presenting sample lessons, evaluating various teacher procedures, conducting simple investigations, utilizing commonplace materials, and constructing simple equipment.

The instructors chosen to teach such courses should perhaps have had some elementary teaching experience, or at least, they should be aware of and have some understanding of the problems of elementary school teaching. Inasmuch as teachers usually teach the way in which they have been taught it is important that the prospective teachers learn how science should be taught by *example* rather than precept.

Acquiring a volume of facts should not be regarded as the sole purpose for science instruction. The prospective teacher who has had all of his science courses in college taught with this major objective, has a difficult time visualizing the teaching of science for any other purpose. How can a teacher encourage the making of hypotheses and shrewd guesses to solve a problem if he has never experienced or seen such teaching demonstrated? The improvement in science instruction must begin at the college level in courses required of prospective teachers.

Furthermore, all prospective teachers should be taught how they can learn by themselves, and they should also be made aware of the necessity for keeping up with scientific advances. The science content they have learned may become outdated by the time they have taught a few years if not before they finish school. This makes it imperative that the teacher plan a program for himself to keep up with the major advances in science.

The AAAS committee report offers three suggestions for improving present college courses: [25]

> a. College science courses should be designed to give a fuller and wider spectrum of science. The courses would probably include materials drawn from several science departments and should teach the logical and operational assumptions on which science is built. The courses need not be specially designed for elementary teachers; those most appropriate for liberal arts majors and other nonscientists might be excellent for prospective teachers in the elementary grades. A working conference to clarify patterns may be useful.
>
> b. Professional education experiences for prospective elementary teachers should include opportunity to observe the work of well qualified teachers who like science and who like children. Prospective teachers should also be provided opportunities to gain experience in formulating questions that are meaningful to children, in developing methods for using quantitative approaches, in using audio-visual and laboratory materials, and in adapting to science instruction materials found in the surroundings of children.
>
> c. All prospective elementary teachers should have an area of concentration. For some, this area should be in science. The teachers who had concentrated in science could then become special science teachers or could assist other teachers less acquainted with science.

Inservice programs. The more common methods for inservice education of teachers have been indicated in the previous chapter as: (1) visitation, (2) workshops, (3) radio and television, (4) conferences, and (5) curriculum. Essentially inservice training is a self-help operation, and administrative encouragement is essential if teachers are to participate in self-improvement programs. Token aid for elementary schools has been available from the National Science Foundation grants. This aid has been used to sponsor summer and inservice institutes for upgrading elementary teachers in the science field.

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[25] "Science Teaching in Elementary and Junior High Schools," Report of a Study by the American Association for the Advancement of Science, *Science*, Vol. 133, No. 3469 (1961), p. 2022.

Science consultants. In view of the specialized nature of many aspects of science, the trend seems to be to employ science specialists to aid the classroom teacher. Some schools have selected teachers with a science interest and labelled them as "Master" or "Key" teachers. These people may teach half the day and assist other teachers during the remaining time by presenting demonstrations, working out science units, arranging for field trips, and obtaining science equipment.

The American Association for the Advancement of Science conducted one of the few studies on the effectiveness of science counselors during the years of 1955—1958. Although this work was done with secondary teachers it is probably applicable to elementary teachers. High school science teachers in the neighborhood of four universities (University of Nebraska, University of Oregon, Pennsylvania State University, and University of Texas) were offered counseling in their science teaching. The evaluation of this study[26] reported in part:

> . . . The only major deficiency noted was that there were not enough counselors to do all the things that needed to be done. Almost universally, the teachers wanted the program continued, and with more counselors. Having been involved in a good thing, many of them even expressed the feeling that such a program should be extended downward to the elementary schools and outward to other, non-science areas.

During interviews the participants were asked what the counselors had done for them. Some of the items listed were:

> (1) providing materials such as demonstration materials, information about new methods, etc.; (2) help with curriculum organization; (3) improved morale (simply having interested and able individuals with whom they could discuss their problems seemed to have given many teachers renewed interest in their work; (4) improved understanding, not only by administrators but on the part of other teachers and university faculty members; and (5) intellectual stimulation. *Many teachers appear to have been feeling a kind of intellectual isolation which the Study helped to reduce.* Asked what the Study ought to do, the commonest reply was "more of the same."

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[26] *Study on the Use of Science Counselors* (Washington, D.C.: American Association for the Advancement of Science, 1959).

Several programs sponsored by the National Science Foundation have been concerned with developing and improving science consultants or supervisors of science. This appears to be a much needed program.

Personal interviews with administrators have outlined the following requirements for a science consultant. The consultant should have a major in a broad science field and possibly a minor in mathematics. He should have had teaching experience preferably in both elementary and secondary fields and he should have had some research experience also. People with such a background are almost impossible to find. Because of the urgency to improve elementary science teaching, the AAAS Committee report has suggested a great increase in the number of summer institutes to develop such leadership in elementary science. They recommend:

> Summer institutes and inservice institutes for elementary and junior high school principals, curriculum directors, science supervisors, special science teachers, and other teachers of known leadership qualities. An important criterion for attendance should be the potentiality of the individual to provide leadership in improving science programs in his own school system.[27]

Summary and a Look Ahead

Scientific knowledge appears to be a common ground for international understanding and it becomes even clearer that leadership among nations will depend upon a nation's scientific knowledge and technology. Thus, fundamental instruction in science beginning as early in life as possible is essential for every individual. Students showing an aptitude for science should be given an opportunity to explore science topics to the limit of their interest and ability. As with a talented musician there should be no real blocks or grade level limitations to impede creative science learning. This certainly seems justifiable when it is known that many outstanding scientists have made their major creative discoveries before they were thirty years of age.

The program of elementary science teaching should develop an interest in and an appreciation of science and provide some of the fundamental scientific knowledge and skills essential to future citizens of our scientifically-oriented society. Science learnings seem to occur on two levels. The first is observational and concerns itself with the description, manipulation, and application of objects. This seems to be the present plateau of most elementary science teaching. The second level of learning is analytical and is concerned with the relationships of phenomena inquiring into *how* and *why* they operate. This second level is more abstract, but experience in this realm is essential if one is to understand the principles of science and appreciate the progress of scientific research. It also seems significant that preliminary studies have shown that elementary students can comprehend some of the more abstract relationships in science. One must conclude then that teachers must be trained to provide such science learnings in our schools.

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[27] *Loc. cit.*

To move ahead in elementary science a clearer picture of the structure and content of science is needed as well as better methods of presentation. Articulation of science between elementary grades and high school must be strengthened and this integration must be related to the training programs of teachers of science in the colleges and universities.

If our students are to have a balanced program of science experiences, a sound curriculum and a sound program for the training of teachers are essential. Although a national curriculum may not be desirable, the national purposes for teaching science should be agreed upon and clearly stated. A curriculum is the strategy for providing a balanced program of science education. Because the science area is so broad in scope and changing so rapidly, it is imperative that practicing scientists be invited to aid in planning and revising curricula by suggesting science content materials and procedures for science studies. This should be done even on the local level of curriculum planning. Such a program will not only assist in upgrading the science curriculum; it will also create more interest in, as well as respect for, the science teaching in elementary schools.

Research is needed on almost all areas of elementary science teaching, but especially in the field of learning scientific concepts and attitudes and in the development of evaluative techniques.

One would like to think that we are finally moving forward in strengthening the science offerings in the public schools, but there is still a lack of understanding of the importance of science to every individual. The following situation seems out of place in a nation that has been challenged as to its educational leadership in the scientific fields:

> It may be hard for some scientists to believe, for example, that the State Board of Education of Minnesota voted in April of this year to eliminate the study of science and mathematics as a requirement for high school graduation. The action, which will become final after a public hearing in July, repealed requirements which were first established only in 1959, and would have become fully effective only with the class of 1963.
>
> Newspaper accounts said the science and mathematics requirements were opposed by principals and student counselors, and by spokesmen for vocational and industrial education, home economics and agricultural groups.
>
> The requirement, it was further observed, prevented counselors from "devising high school programs suited to the individual student!" [28]

Perhaps never before in the history of this century has there been such general concern and earnest effort to improve the pattern of public education and especially in the fields of science and mathematics. Science educators must coordinate their efforts with related groups to formulate a sound forward moving elementary science program in the elementary grades, yet never losing sight of the following:

> Science is not just an accumulation of facts; indeed, the "facts" of science today may not be facts tomorrow. Science is a composite of observations, facts, definitions, concepts, laws, principles, and theories. But perhaps more important are its components of attitudes and modes of reasoning which lead to the organizations and the applications thereof. Science is descriptive, analytical, and synthetic. It is both quantitative and verbal. No individual truly learns science who learns only the results of scientific activity; he must grasp the rules, logic, and procedure which characterize that activity. In a word, he must become, to a degree, scientific.[29]

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[28] Newsletter of American Institute of Biological Sciences, Washington, D.C., May, 1962, Vol. 3, No. 3.

[29] National Society for the Study of Education, *Rethinking Science Education*, 59th Yearbook, Part I (Chicago, Ill.: University of Chicago Press, 1960), p. 62.

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APPENDIX

Topical List of Science Concepts

The following represents the major concepts and principles as well as the scope of some large science areas. These were drawn up several years ago for use in an elementary science workshop. They have proved useful as a start toward the preparation of science curricular materials.

Physical Sciences

Energy. Energy may be thought of as the ability to do work, such as lifting weights, heating materials, or winding up springs. All movements on the earth require the expenditure of energy. Man's sources of energy include animal-power, fuels of all kinds, moving air and water, and the nuclei of certain kinds of atoms. Directly or indirectly, essentially all our energy comes from the sun, where it is produced by nuclear synthesis. Increasing world population, decreasing supplies of mineral fuels, and rising standards of living make it necessary for man to look at the atom as an energy source, and beyond that to the sun, unless he is to revert to an agricultural and nomadic existence.

Conservation of matter and energy. Not so many years ago, scientists pointed with finality to two powerful generalizations in physical science—the Law of Conservation of Energy and the Law of Conservation of Matter. The former could be stated, "Energy can be neither created nor destroyed, but can be changed from one form to another." A parallel statement could be made for matter. Today we know that matter and energy are interchangeable—one can be changed to the other. It might be said that matter and energy are two manifestations of the same entity. In simple chemical changes, such as burning, the quantity of matter converted into energy is so small as to be completely beyond our means of detection. In a nuclear explosion—such as an atomic or hydrogen bomb (fission or fusion)—a small fraction of the original bomb's active ingredients is actually converted into energy. The energy released by the sun derives from conversion each second of about 400 tons of matter into energy.

Heat and temperature. Heat is a form of energy commonly derived from chemical reactions—notably the burning of fuels—from mechanical friction, electric current, solar radiation, and from changes in the nuclei of certain kinds of atoms. The measure of heat quantity is the calorie, although other units are also used. The heat energy in any material is due to the motion (kinetic energy) of its molecules—the more heat the more molecular activity. Changes in the heat energy of a material result in changes in its temperature, size, physical state, and/or chemical composition. Temperature, the measure of heat intensity, is measured in degrees on the Fahrenheit (or in many science activities, the Centigrade) scale. Heat may be transferred from one place to another by conduction, convection, or radiation. Man controls this heat transfer to his own advantage in clothing, cooking utensils, and household heating systems, among others.

Light and color. Light is a form of energy supplied by the sun, most flames, electric lamps, and a few chemicals. Light travels extremely fast (virtually instantaneous over earthly distances). It goes in straight lines except when it bounces (reflects) from surfaces or bends (refracts) when it travels from one transparent substance to another. Reflection and refraction of light produce natural phenomena such as human vision and rainbows, and man-made optical devices such as telescopes, eyeglasses, projectors, and cameras. Our eyes are sensitive to many colors of light—the "rainbow's seven" and numerous others. White light contains many colors; two or more colors can be mixed to produce different colors, including white.

Electricity. Electricity is a fundamental characteristic of the universe and is manifest all the way from interstellar space to the nucleus of the atom. Electric charges are of two kinds, "positive" and "negative." Unlike charges attract each other; like charges repel. An electric current in a wire is a flow of electrons (negative charges). Electricity is not a *source,* but merely a form of energy. The current acts as an energy carrier, conveying energy from a source (cells, generators, etc.) to the user (lamp, heater, motor, etc.). Electricity is useful to man because it is easily transported over relatively long distances, because it is easily controlled, and because it can be readily converted to and from other energy forms. Electricity has done much to raise our standards of living, to ease the drudgery of housework and the dirt and danger of factories, and to shrink the geographic world through means of communication and transportation. Man's study of electricity has also helped him better understand and control the fundamental behavior of matter.

Magnetism. Magnetism is a fundamental property of matter, and is exhibited in all forms of matter from the atom to the galaxy. Magnets attract nearly all things made of iron or steel, nickel or cobalt. A magnet needs only to *be near* iron objects to attract them; it need not touch them. Hence, we say the magnet is surrounded by a *magnetic field*. All magnets exhibit two poles (occasionally more) commonly referred to as "North" and "South" ("N" and "S"). Unlike poles of magnets attract each other; like poles repel. The earth behaves as though it contained a giant magnet; a compass needle points generally in a north-south direction because it is influenced by this "earth-magnet." Electric currents have magnetic properties, which make possible electromagnets. These can be turned on or off at will, and their magnetic polarity can be easily reversed. As a result, electromagnets are widely used in electric telegraphs, telephones, radios, motors, and similar devices.

Gravitation. Gravitation is a universal phenomenon—one fundamental to the nature of the physical world. According to the "law of gravitation," every object in the universe attracts every other object with a force that depends on the mass of the objects and on the distance between them. This principle applies on our planet and also in interstellar space—to specific objects and to bodies of liquid or gas as well. The weight of everyday materials is due to gravitation; the force of gravitation helps hold the planets and satellites in their orbits, and the stars in huge clusters called galaxies.

Sound and music. Sound is vibration. Sound is produced by vibrating materials and is transferred by the vibration of molecules of air and other substances. Sound provides a means for communication of emotions and ideas. Musical instruments have objects or bodies of air which vibrate and produce notes of variable but controlled frequency (pitch), amplitude (loudness), and pattern (quality). Large, heavy objects produce lower notes (lower frequency vibrations) than small, light objects. The human voice and other natural sounds, including noises, are less distinctly organized than musical sounds. Sound travels a mile in about five seconds. Sound can be directed by means of megaphones and horns, and reduced by sound-absorbing (acoustic) surfaces. Modern science has developed ways to record and reproduce sound, to transmit it (electrically) over long distances, and to amplify (electronically) weak sounds into strong ones.

Machines and engines. Man has invented many ways of making difficult work easier, or impossible tasks possible. Some of these techniques, such as wheels and lubrication, are merely ways of reducing energy losses due to friction. Certain devices known as "simple machines" (*e.g.*, levers, inclined planes) permit a small exerted force to overcome a relatively large resistance. Engines, on the other hand, deliver mechanical work from some non-mechanical energy source, as in the case of steam or gasoline engines and electric motors. The development of civilized man from a savage, the changes wrought in the industrial revolution, and the modern age of science are to a large degree based on man's ability to control force and energy through the use of machines and engines.

Basic nature of matter. All physical substance falls into the category of *matter*. A child might refer to matter as "stuff." Matter occupies space, possesses mass, is electrical in character, exhibits elasticity, and often exhibits color, shape, odor, texture, etc. Fundamentally, all matter is made up of a limited number of different kinds of "basic building blocks." Among these, the three most important are the electron, the neutron, and the proton. By learning more and more of the basic nature of matter, mankind understands better the world in which he finds himself and is also better able to use, control, and appreciate the matter of which he is constituted and by which he is surrounded.

Molecular nature of matter. When a given variety of matter is (ideally) subdivided and resubdivided until a single unit of that variety of matter remains, this single unit is the molecule. (In the case of an element, this is often the atom.) A knowledge of this molecular nature of matter helps man understand its behavior.

Thus, expansion due to heat is evidence of increased molecular activity, and hence a need for more space. Sound consists of and is carried by molecular vibrations. The degree of molecular activity of a substance determines its physical state (solid, liquid, or gas). Thus, low molecular activity in a material tends to render it a solid. Increased activity produces the characteristic of a liquid. Highly active molecules take on the character of a gas. Almost all chemical reactions involve chemical changes among the molecules. Molecules are extremely small, far beyond the range of a lens-microscope. However, "indirect evidence" of some larger molecules' existence and structure has been obtained through the use of the electron microscope. In matter—even in solids—there is a great deal of space among molecules. Actually, the space among molecular and sub-molecular particles far exceeds the space occupied by the particles themselves.

Chemical elements. Although there are seemingly numberless different kinds of matter—*i.e.*, different kinds of chemical substances—in existence, these can be shown to be made up of combinations of some 101 basic chemical materials known as elements. Of these, 92 occur in nature, while the other nine (as of this writing) are artificially produced, and often of only fleeting existence. Just as the molecule is the basic "building block" of any material, so the atom is the basic "building block" of an element. Many of the elements are household words, *i.e.*, iron, copper, gold, silver, oxygen, nitrogen, hydrogen, chlorine, mercury, phosphorus, arsenic, and uranium. When two or more elements are combined in fixed proportions, they usually lose their respective elemental physical properties and become a new chemical material known as a compound. Many common materials (air, wood, flesh, earth) are mixtures (merely scrambled together and not in fixed proportions) of two or more elements or compounds. The elements may be arranged in a logical and instructive arrangement, often in chart form referred to as the "periodic chart of the elements." Most elements have a few or several "forms." All the "forms" of a given element are its "isotopes." Isotopes of a given element have slightly different weights and sometimes markedly different nuclear activity patterns. However, they all have the same chemical characteristics.

Chemical Changes. Chemical changes are rearrangements of atoms, as when elements combine to form compounds, when compounds disintegrate to form elements, or when compounds undergo mutual changes to form new sets of compounds. Chemical changes either give off or absorb energy. When they give off energy (are exothermic) they produce light, heat, electricity, or some other form of radiant energy. When fuels burn, they combine with the oxygen of the atmosphere and give off energy for heating or for producing motion in engines. The life processes of food manufacture and digestion, of respiration and metabolism, of growth and excretion are all chemical in nature. Chemists, working with chemical changes have learned to make countless new products—plastics, drugs, dyes, etc. —which have drastically altered our pattern of living.

Weather and weather forecasting. Weather, the daily changes in the state of the atmosphere, plays an important role in the lives and activities of people. Weather phenomena involve vast energy changes in terms of heating the atmosphere and the movement of air. The condition of the atmosphere with respect to pressure, temperature, and moisture varies considerably from place to place and from time to time. Through knowing the condition of masses of air, direction of movement, and through interpretive experience, trained personnel—the meteorologists—can predict weather fairly accurately. The average of weather, or climate, determines the living and working patterns of the people.

Changes in the earth's surface. Since its formation perhaps five billion years ago, the surface of the earth has been—and still is—continuously changing. Processes related to temperature change, erosion, and chemical change have contributed to the building up and the wearing away of land. All the physiographic formations of the earth have evolved through these kinds of processes. An understanding of these principles contributes to one's utilization and enjoyment of the earth's contents and form.

Mechanics of the universe. There is a definite orderliness in the motions of the bodies within the universe. Man has come to depend upon the predictability of these motions and has utilized his knowledge to devise precise units of time. Such phenomena as tides, eclipses, climate, planetary movements, time, and gravitational attraction are related to the mechanics of the universe. Man is constantly increasing his knowledge of the mechanical nature of the wider universe. He is hard at work to try to conquer space in a physical sense.

Tools of science—measurement. Science has advanced partly because of the scientists' ability to measure, weigh, and use tools. Measurements of all kinds may either be gross or, as is more generally the case, highly refined. This requires tools of measurement commensurate with desired precision. Systems of measurements have evolved which are understood throughout all the world by all scientists. Much of science and scientific procedure has been standardized against the various measuring devices and systems. As new tools are developed, the frontiers of scientific knowledge and advancement are extended. The application of science to human progress (technology) also depends upon numerous tools of all kinds.

Material resources of mankind. The earth is a vast storehouse which supplies the material resources for man. From the basic building blocks (the 92 naturally-occurring elements) are made the minerals, ores, and life-giving water. Man has learned to winnow from the ground, the sea, and the air the raw materials of most of the products he uses in daily life. He is faced with the very important problem of wise use and conservation of his resources.

Energy resources of mankind. Energy is the capacity to do work. It has several forms including heat, electrical, chemical, mechanical, and atomic. The primary source of available and useable energy comes directly or indirectly from the sun, a vast reservoir. Fuels (coal, oil, gas, wood) received their initial energy from the sun long years ago in the form of plant and animal materials. Man is discovering how to unlock the secret of the atom to furnish vast amounts of energy. He is also faced with the social problem of equitable sharing of the use and control of energy.

Force and motion. Mechanical force may be thought of as a push or a pull. In everyday living, forces are exerted, for example, by gravitation, by electricity or magnetism, by steam or other examples of thermal expansion, and by muscular effort. Mechanical force is required to change the size or shape of any material and to change the magnitude or direction of a body's motion. The movements of projectiles, freely falling bodies, skidding automobiles, and planets and stars can be understood and predicted in terms of their masses and the forces acting upon them.

Biological Sciences

Life is described in terms of functions. Life cannot be readily defined; it can best be described in terms of a unique assemblage of functions or activities, which are not found in such complex association in non-living systems.

1. Living organisms exhibit certain common phenomena: growth and reproduction, irritability, autonomous movement, metabolism, and hereditary continuity and variability.
2. The great diversity in the size, structure, and habits of living organisms results from the varying means by which these phenomena of life are expressed.
3. Viruses may represent the borderline between life and non-life, performing some, but not all, of the functions usually associated with life.

Protoplasm—the basis of life. Protoplasm is the physical-chemical basis of all life.

1. Protoplasm is unique in its organization; it is an incompletely known physical and chemical system, with some properties common to non-living systems, but with a total complex of properties peculiar only to itself.
2. Water is the solvent for protoplasm, and therefore for the nutrients normally used by protoplasm—it is the "universal solvent" for life's processes.

The cell, the unit of life. Most organisms are composed of relatively small structural and functional units known as cells.

1. Structurally, most living cells are characterized by certain internal elements; they also are subject to definite limitations upon increase in size, which relate to transport of nutrients and cellular products as influenced by critical surface-volume ratios.
2. Functionally, every living cell acts to some extent as an individual; it carries out all the activities of life, employing (most notably) a selectively permeable cell membrane, and internal enzyme systems for these functions. However, the cell is not a closed system; it depends upon an external source of energy and is constantly reacting with its environment.
3. Most cells contain in their nucleonic elements the determiners (genes) for the characterisitcs of the organism as a whole, and therefore maintain a continuity of inherent characters from cell to

cell within the developing organism, and from generation to generation.

4. Many cells exhibit special capacities for growth and repair, for differentiation to perform highly specialized functions, or for differentiation to an essentially generalized embryonic condition.

The organismic concept. The living organism is more than a mere aggregate of independently functioning cells; its complex functions are the resultant of coordinated interaction of functions of all its component cells.

1. Life functions are in accordance with the basic physical laws of matter and energy, and may be considered at the cellular, tissue, organ-system, or organism level of organization.
2. Homeostasis, a state of dynamic physico-chemical equilibrium, is characteristic of a healthy normal organism and can be demonstrated at all levels of organization.
3. Increase in size among organisms is correlated with increasing problems of functional integration and with the evolution of specialized organ-systems which serve these integrative functions.
4. Learning represents a complex integrative function about which very little is known.

Energy transfer and release through photosynthesis and metabolism. Energy required by living organisms is derived ultimately from the sun, and its utilization involves complex transformations via the processes of photosynthesis and metabolism.

1. Green plants "trap" and store energy from the sun by building large molecules out of small ones, thus producing a continuously renewed source of reduced compounds, for the metabolic needs of both plants and animals.
2. Energy and matter are neither created nor destroyed by life's processes; rather they are transferred and transformed as they pass in succession though elements of the food chain.
3. Organisms release energy by breaking large molecules (reduced compounds) into smaller ones (oxidized compounds). This process (metabolism) involves:
    a. enzyme systems inside and outside the cells.
    b. chemical oxidation (removal of hydrogen from the large molecules).
    c. energy-transfer mechanisms in the form of energy-rich bonds.
    d. energy spending processes (*e.g.*, heating or moving an organism, building up new molecules, etc.).

Growth and reproduction phenomena. Growth and reproduction occur in all organisms according to a common fundamental pattern; however, many forms exhibit special phenomena functionally related to the mode of life of those organisms and to the exigencies of their environments.

1. Growth and repair are functionally related processes, intergrading in the vegetative propagation of plants.
2. Growth and repair are functionally related processes, and include such phenomena as differentiation and dedifferentiation of tissues and regeneration of lost tissues and parts.
3. Growth and reproduction in all organisms derive from the common properties of all living cells, including size limitations as related to nutritional needs, and surface-volume ratio.
4. Growth and reproduction in all organisms result from specific mechanisms of all divisions which are governed by specific organelles and properties inherent to living cells.
5. Continuity of the germ plasm insures the continuity of the race, despite the exigencies of growth processes, or the impacts of the environment upon the somatic cells of the individual.
6. Sexuality and its resultant opportunities for genetic recombinations constituted a major evolutionary development in the history of life on the earth.
7. Gametogenesis involves basic mechanisms common to all sexual organisms. Sexual and phyletic deviations from this fundamental process are related to the functions of the gametes produced.
8. Growth and reproduction among certain organisms are characterized by special phenomena which relate to the survival of the species under specific environmental pressures. Such phenomena include metamorphosis, metagenesis, parthenogenesis, and neoteny.

All life from life. Since the beginnings of life on earth, all forms of life, living and extinct, have descended from pre-existing life and owe their form to the continuity and mutability of the germ plasm.

1. Spontaneous generation of life from non-life has never been demonstrated. In spite of this, it is presumed that life did originate spontaneously in the very distant past, under conditions not now found in nature on the earth.
2. Heritable continuity of life is maintained by the chromosomes and their corporate genes. Chromosomes seem to be chains of nucleic acids which both duplicate themselves and synthesize enzymes.
3. Variation in heritable characteristics, with a consequent pro-

duction of new forms, results from mutations and recombinations of chromosomes and their genes.

4. Hereditary continuity and variability are governed by fundamental genetic mechanisms, in accordance with laws of probability; survival of lineages depends upon the interaction of genetically induced characteristics with the selectively limiting factors of the environment.

5. Man selects genetically induced variants for the production of desired qualities in domestic plants and animals.

Classification and the species concept. Living things are classified by man according to their presumed phylogenetic relationships —their inferred descent from common ancestry. This system rests upon several premises, among which are:

1. The species is a population which can be objectively delimited and described, though it is difficult to define categorically.
   a. A "biological species" is a natural self-sustained population, actually or potentially interbreeding, and reproductively isolated from similar populations.
   b. A "taxonomic" or "morphological species" may of necessity be established by a competent systematist on a basis of morphological distinctions alone, where other biological data are lacking.
2. Higher categories in the taxonomic system are inferential, based upon presumed common origins of their contained species. These judgments are derived from combined evidences of comparative embryology, morphology, and biochemistry, and from biogeography and paleontology.
3. Classification utilizes today a well defined and internationally accepted system of biological nomenclature.

Evolution. Living organisms on earth today represent the current time segment in a continuing process of change called organic evolution.

1. The raw materials for evolutionary processes are provided by mutation and recombination of chromosomes and their genes.
2. Guidance of the evolutionary process is provided by the selective forces of the environment, with genetic variants being preserved or rejected according to their quantitative degree of fitness for that particular environment.
3. Speciation—the establishment of a species as a distinct biological entity—depends upon the evolution of reproductively iso-

lating mechanisms, which may be geographic, morphological, psychological, chronological, or ecological.

4. Evolutionary processes are complicated in certain groups by such intrinsic factors as interspecific hybridization, polyploidy, and apomixis.

5. Evolutionary processes are complicated also by certain extrinsic factors, such as geological and climatological changes in physical and biotic environments.

6. Evolution within any given group proceeds within the bounds of certain limitations, which are apparently the product of the evolutionary history of that group.

7. Certain assumptions which are more or less generally true have shaped the interpretation of evolutionary processes. Among these are:

   a. Ontogeny recapitulates phylogeny (modern interpretation).
   b. Acquired characteristics are not inherited.
   c. Complex forms are evolved from less complex ancestors.

Interrelationship of living things. Organisms are interrelated according to complex biological patterns, producing a "web of life" which often functions as an inter-species entity.

1. Organisms rarely are independent of other organisms, and biotic relationships rarely are coincidental.

2. Relationships at the individual level may be classed as symbiotic (in the broad sense), involving:

   a. predation
   b. parasitism
   c. mutualism
   d. commensalism

3. Relationships considered at the population level involve societies, communities, biomes, etc., and are subject to complex population factors.

4. All biotic relationships must be considered in the context of the physical limiting factors of their environment.

5. Man as an animal is affected by all these factors; his efforts to manipulate his environment do not change the basic principles involved; they only modify the conditions under which those principles operate.

Distribution in space and time. Distribution of plants and animals over the earth always has resulted from the interaction of two forces: first, the (adaptive) survival capacities of any given population, and second, the limiting factors of the physical and biological environment of that population.

1. Survival capacities of a population result from general plasticity of that population. This may be physiological involving wide tolerances of varying environmental conditions, or it may be genetic, involving great hereditary variability.

2. Environmental factors which may limit survival and distribution of organisms may be *physical* (*e.g.*, temperature, moisture, light, fire, etc.) or *biotic* (*e.g.*, natural enemies, disease, food supply, lebensraum, etc.).

3. Changes with time in environmental conditions usually force one of three responses upon affected populations:
   a. survival as result of "adaptive" responses to the environment.
   b. migration to more suitable environment.
   c. eventual extinction due to inability either to adapt or to immigrate.

Method of science. The modern science of biology is a heritage 25 centuries in the making. It progresses today through intelligent use of a method which has both inductive and deductive components, and which places major reliance upon objectively derived data, interpreted in the light of accepted physical laws.

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